

High Energy Emission from GRB

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For a few seconds, a GRB
dominates the gamma-ray brightness
of the entire Universe

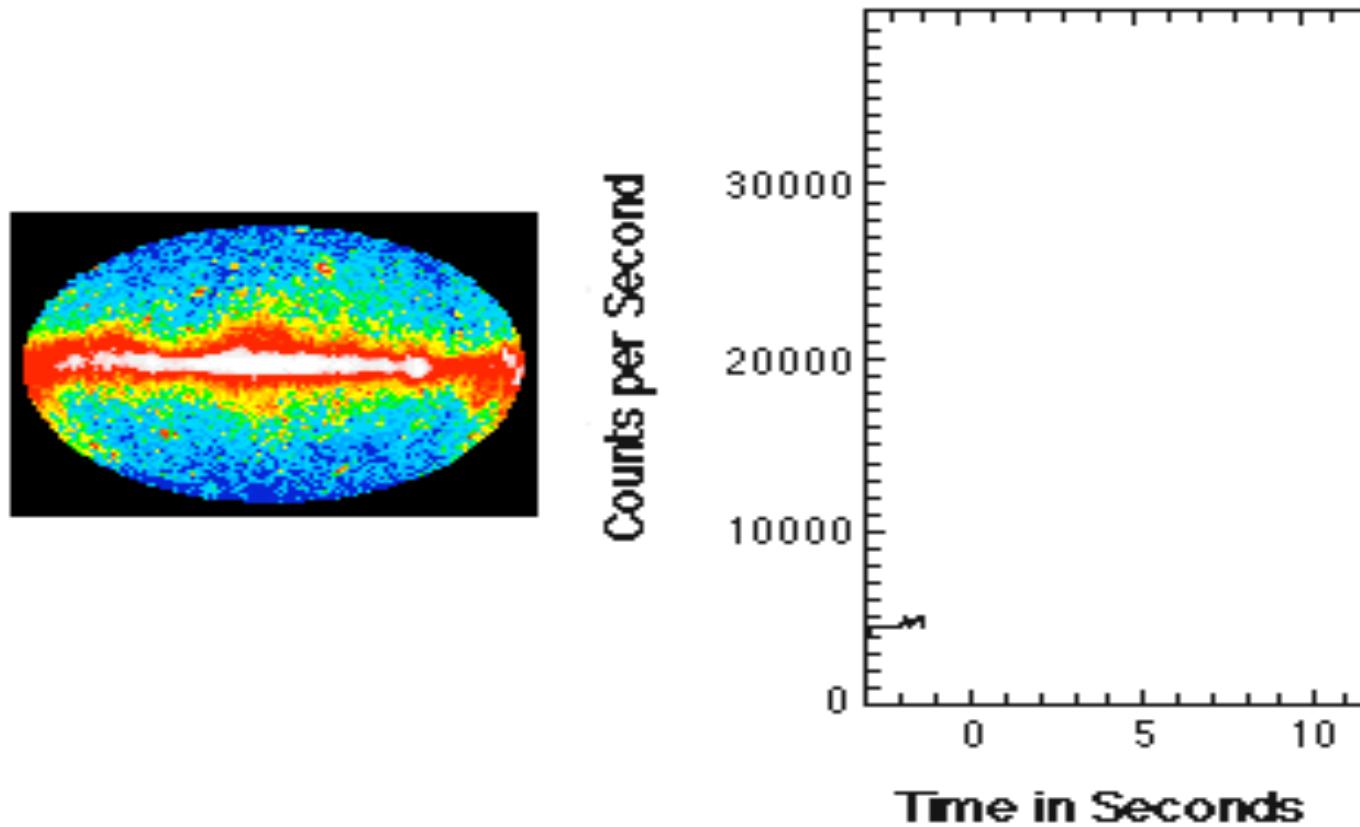


Fig. Credit: Tyce DeYoung

GRB: *basic numbers*

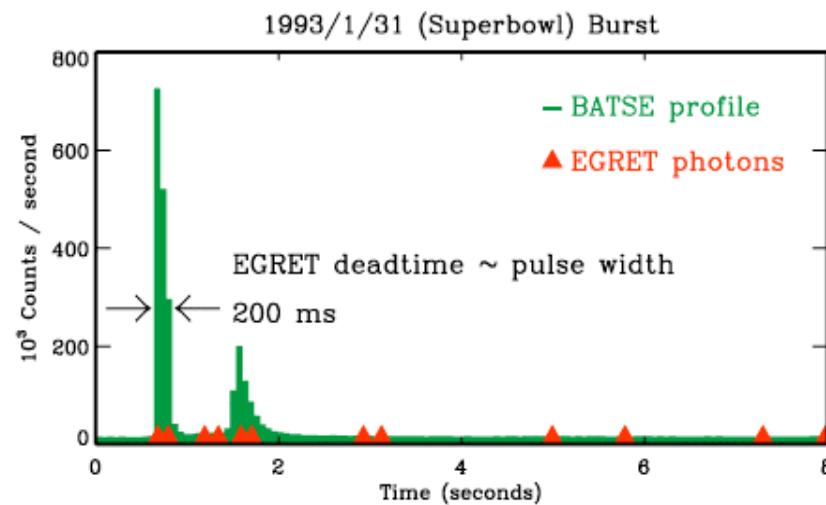
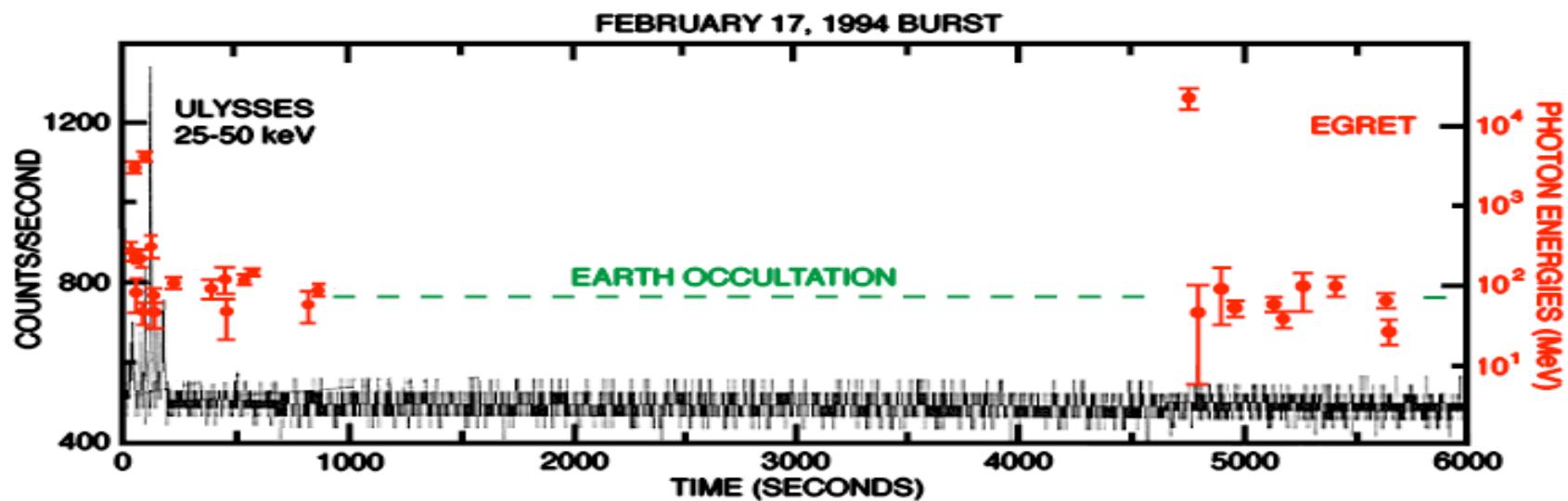
- Rate: $\sim 1/\text{day}$ inside a Hubble radius
- Distance: $0.1 \leq z \leq \mathbf{6.3} !$ $\rightarrow D \sim 10^{28} \text{ cm}$
- Fluence: $F = \int flux.dt$ $\sim 10^{-4} - 10^{-7} \text{ erg/cm}^2$
 $\sim 1 \text{ ph/cm}^2 (\gamma\text{-rays} !)$
- Energy output: $10^{53} (\Omega/4\pi) D_{28.5}^2 F_{-5} \text{ erg}$

$$\text{jet: } (\Omega_j/4\pi) \sim 10^{-2} \rightarrow E_{\gamma,\text{tot}} \sim 10^{51} \text{ erg}$$

$$E_{\gamma,\text{tot}} \sim L_\odot \times 10^{10} \text{ year} \sim L_{\text{gal}} \times 1 \text{ year}$$

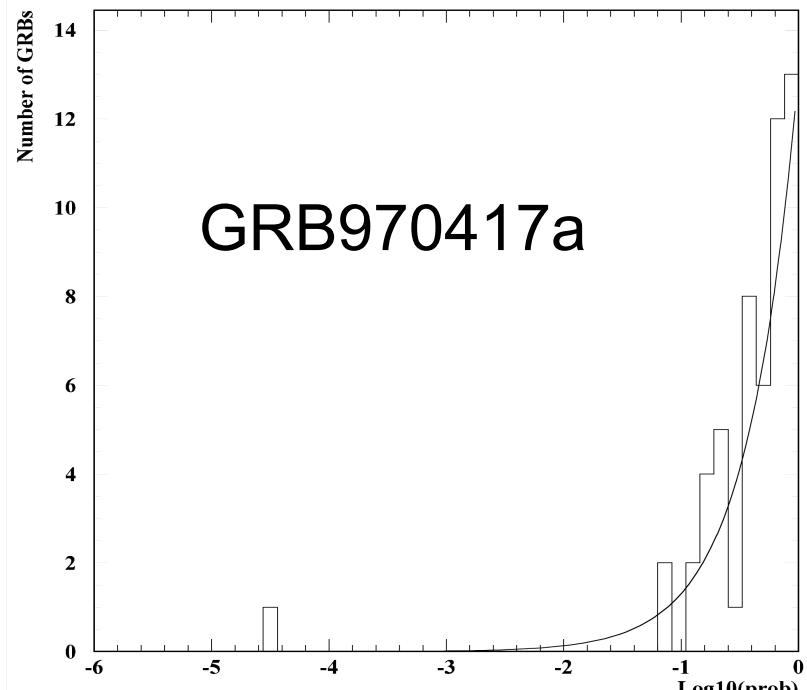
- Rate(GRB) $\sim 10^{-6}(2\pi/\Omega) / \text{yr/gal} \rightarrow 1/\text{day} (z \leq 3)$
whereas Rate [SN] $\sim 10^{-2}/\text{yr/gal}$, or $10^7 / \text{yr} \sim 1/\text{s} (z < 3)$

Two EGRET (GeV) Bursts



- >10 GeV photons can last for > 1 hr, start w. MeV trigger
- Considerable energy at 100 MeV-10 GeV

TeV GRB Detection Status



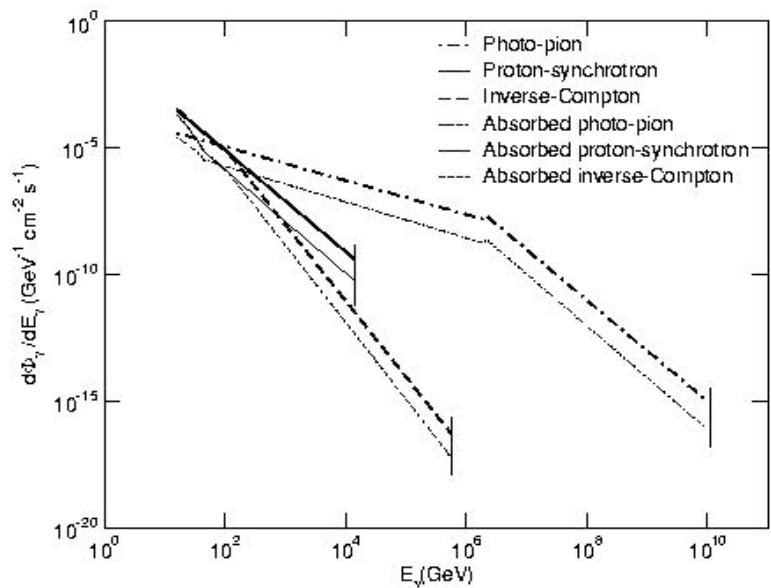
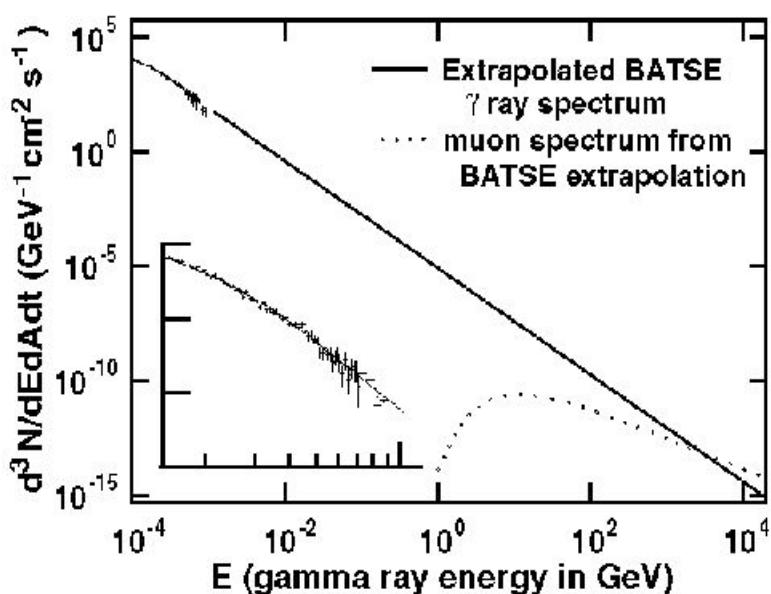
- **Milagrito** : Tentative (3σ) TeV detection ;
 $\Phi_{\text{TeV}} \sim 10 \Phi_{\text{MeV}}$; but no z (abs? $d < 100$ Mpc?)
Atkins et al, 00, ApJL..
- **Tibet** array: superpose 50-60 \neq bursts in time-coincid. w. MeV: joint significance 7σ ?

Fig. 1.— Distribution of probabilities that the observed excess no. of events at the candidate TeV position was a background fluctuation, for each of the 54 bursts. The curve indicates the expected prob. distr. for a sample drawn from background. The entry at -4.5 corresponds to GRB 970417a.

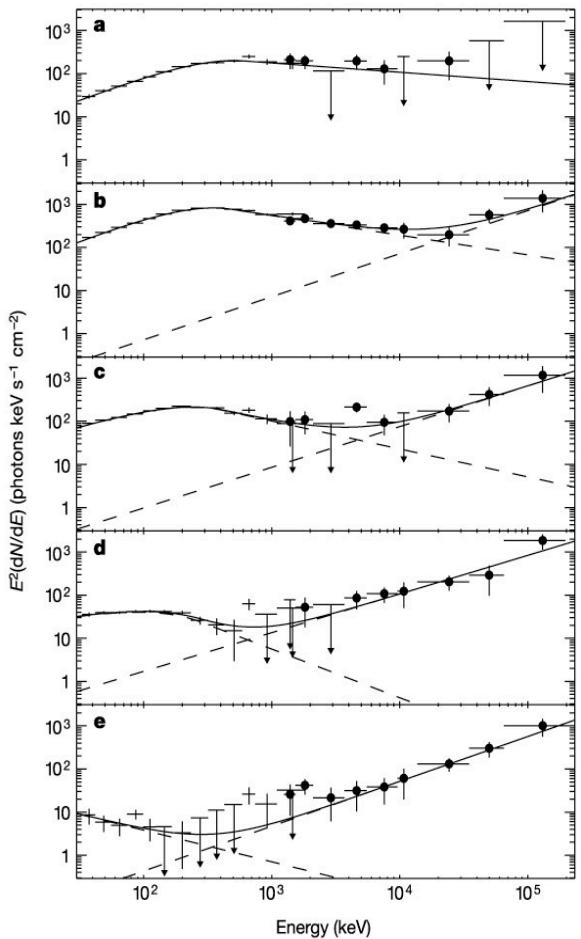
(Amenomori et al 01)

TeV GRB detection status (cont.)

- **GRAND**: grb971110 reported at **2.7σ**
(Poirier et al PRD 03, [aph/0004379](#))
- modeling requires various assumptions, some severe (Fragile et al 03):
 $z \sim 0.7$, maximize proton contrib.
(and total energetics)
 $U_p = (m_p/m_e) U_\gamma \sim 10^{56}$ erg !
(isotr.eq.), $B \sim 10^5$ G, $p=2$
(see also Totani '98, ApJ 509, L81; '99, 511, 41)
 $p\gamma$, p-sy, e-IC, w.(thin) / w.o(thick) internal $\gamma\gamma$ absorpt.



GRB 941017 : p γ signature?



t < 14 s

t < 47 s

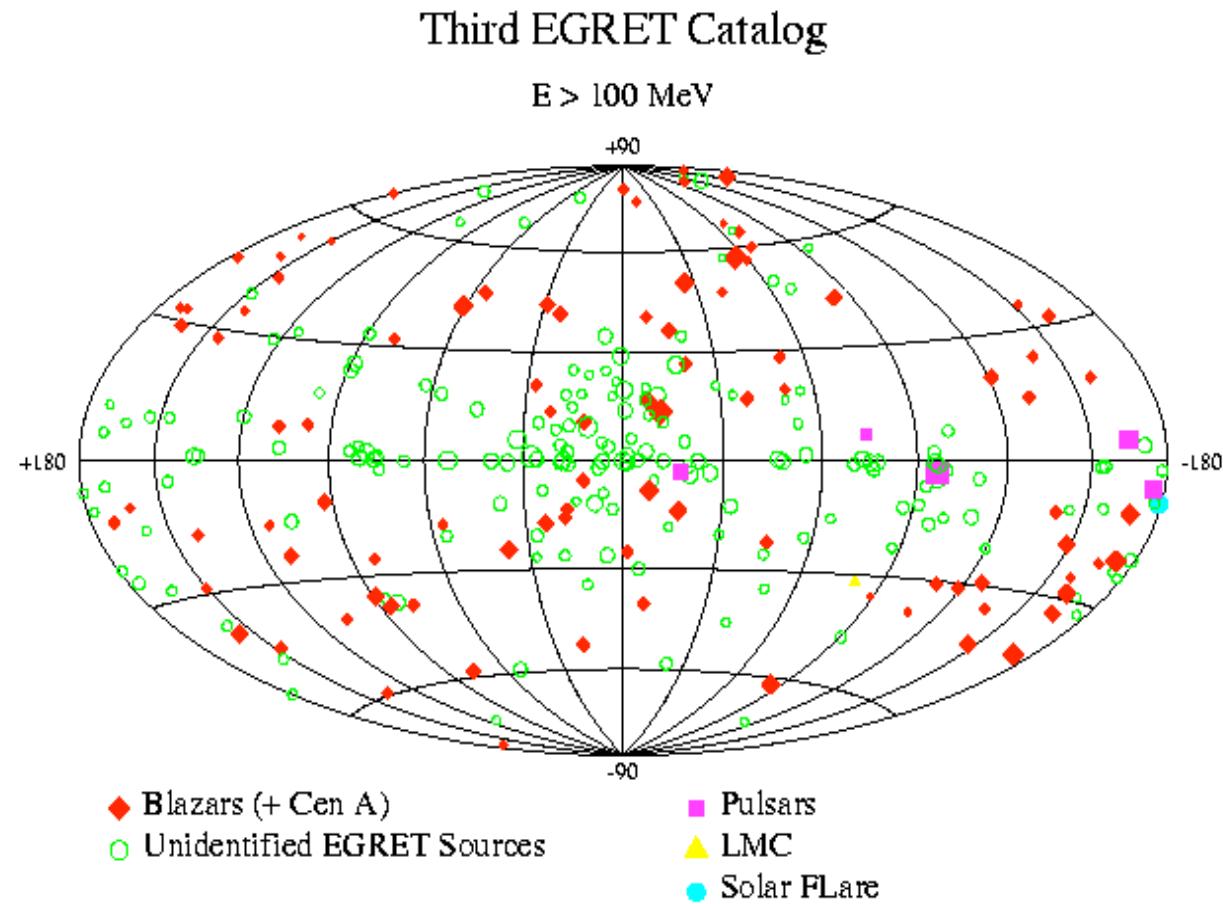
t < 80 s

t < 113 s

t < 211 s

- Hard (**10-200 MeV**) comp. in EGRET TASC calorimeter **not** compatible w. BATSE MeV fit (but in 26 other bursts a single BATSE/TASC fit works well)
- Hard comp. more prominent in time → **p γ signature?** might explain delay, hardness (also Dermer, Atoyan 04 AIPC 727, 557)
- **Alternative: could be IC**, in regime where IC sp is harder than sync PL ; e.g. scatt. of lower energy synch. asymptote; or observe IC region where electrons with a range of energies scatter off a range of photon energies (Granot,Guetta, astroph/0309231; Pe'er, Waxman, 04)

Gonzalez, Dingus et al, 03, Nature 424, 749



GeV γ
from
Blazars,
PSRs,
GRB
(and other gal. &
un-ID sources)

- EGRET(space): 66 + 27 blazars , 5 PSRs, 4 GRB @ 1-10GeV,
- ACTs (ground): HESS, Whipple, HEGRA, CAT, CANGAROO...:
 $> 8 \text{ AGN}, > 4 \text{ SNRs} @ > 10 \text{ TeV}$

GeV-TeV γ experiments underway



MILAGRO

Cherenkov
Telescopes

← Water

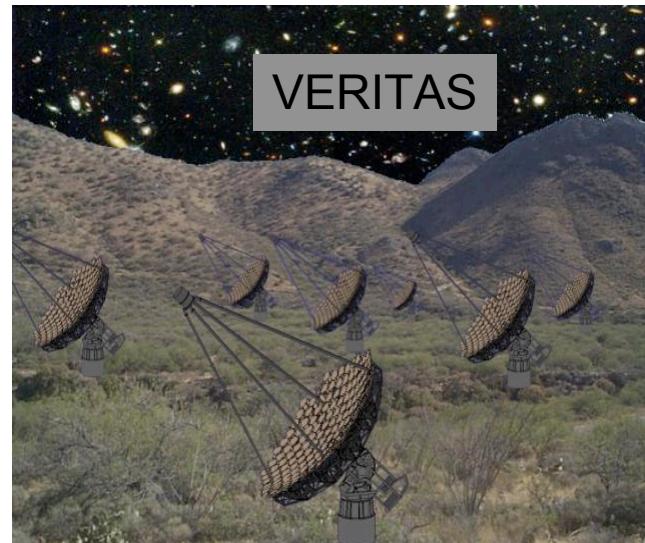
Air →
↓ ↓



HESS



Cangaroo



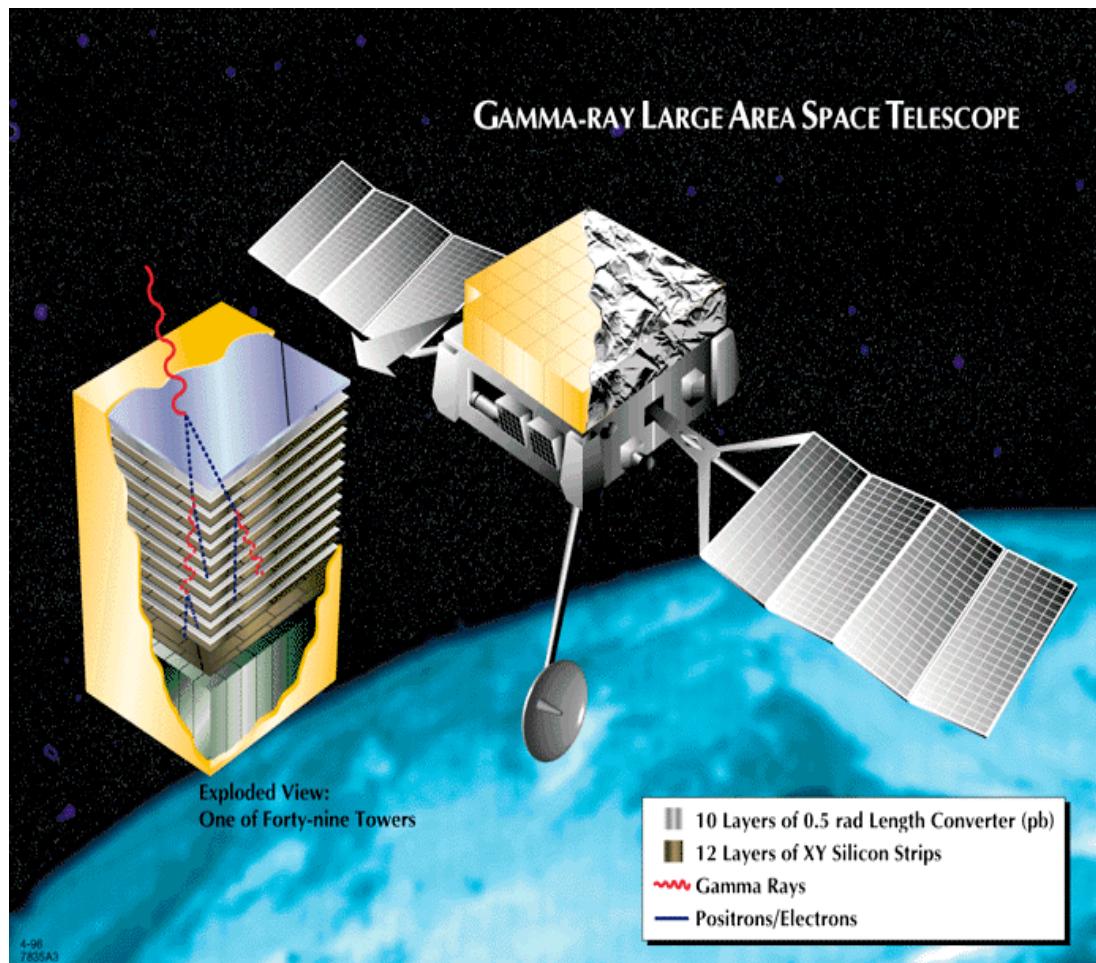
VERITAS



MAGIC
& HEGRA

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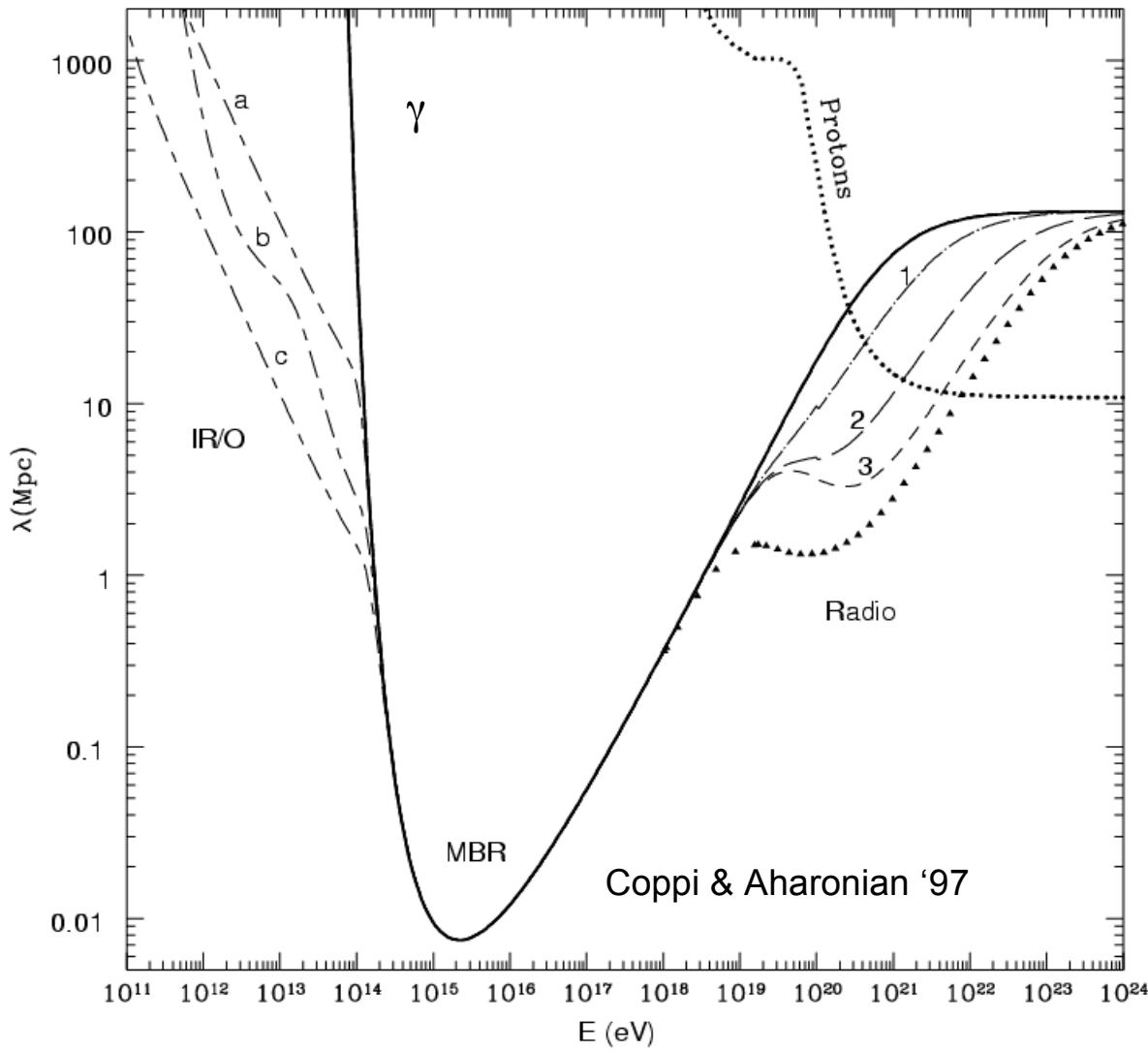
GLAST : LAT (Stanford +)



- LAT: launch exp '07, Delta II, 2-300 GRB/2yr
- Pair-conv.mod+calor.
- 20 MeV-300 GeV, $\Delta E/E \sim 10\% @ 1 \text{ GeV}$
- fov=2.5 sr (2xEgret), $\theta \sim 30'' - 5'$ (10 GeV)
- Sens $\sim 2 \cdot 10^{-9} \text{ ph/cm}^2/\text{s}$ (2 yr; $> 50 \times \text{Egret}$)
- 2.5 ton, 518 W

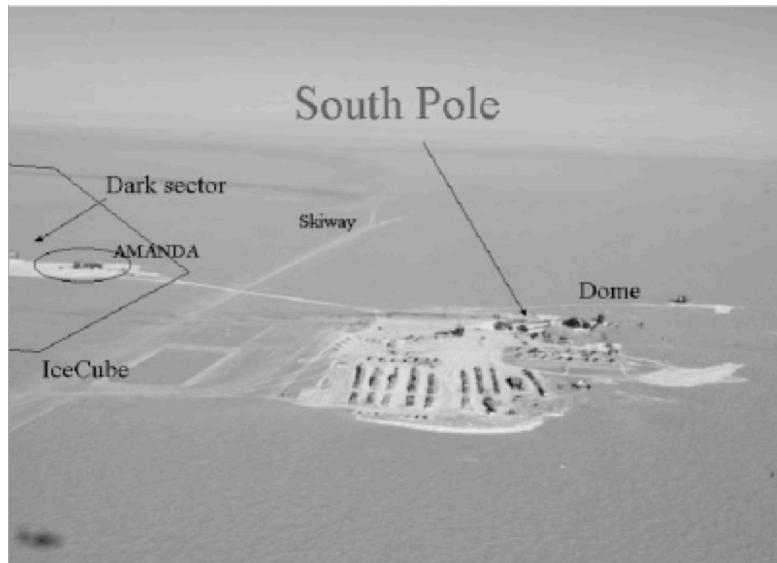
Also on GLAST: GBM (~BATSE range)

$\gamma\gamma$ Opacity of the Universe

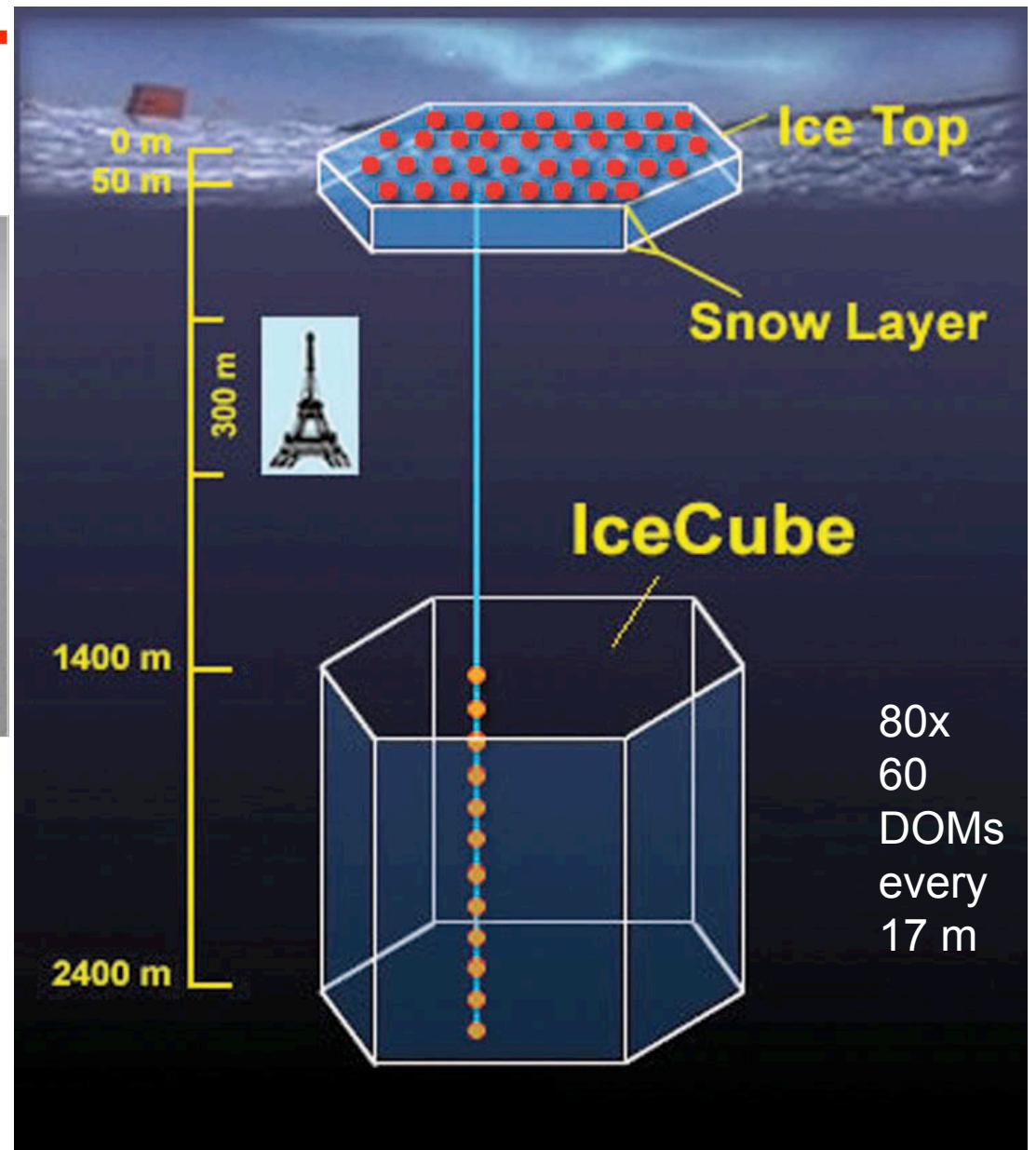


- All but the densest (veiled) AGN sources (e.g. gal.nuc?) are **transparent**, $\tau_{\gamma\gamma} < 1$, for $>\text{TeV}$ γ s on “**local**” target photons,
- but..
- Intergalactic medium is **opaque**, $\tau_{\gamma\gamma} \geq 1$, for $>\text{TeV}$ γ on **IR bkg** γ (D<100-500 Mpc)
→ test IR bkg sp. density,
- constrain early star formation rate & z-distr of SFR, LSS, cosmology

ICECUBE: km³

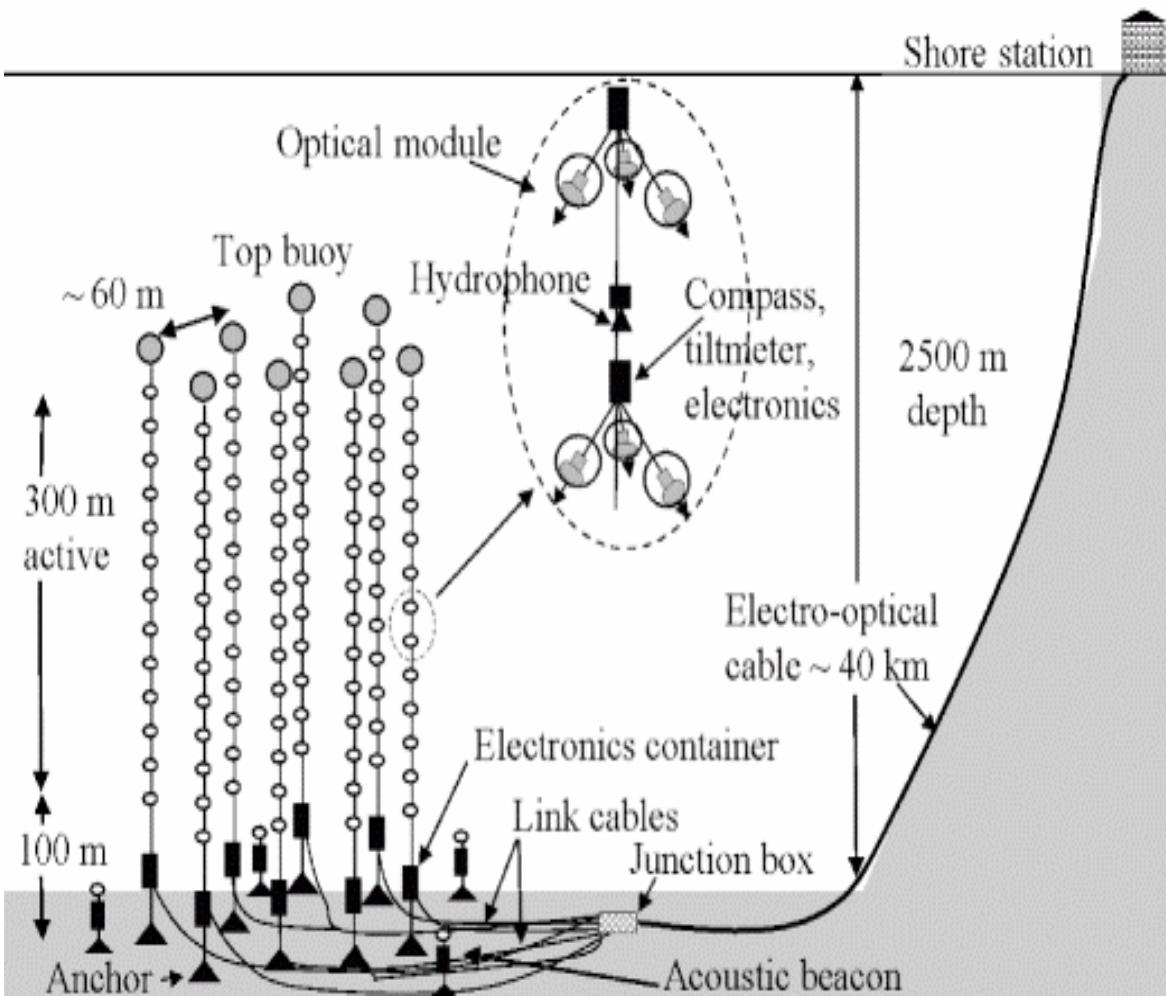


- Extension of Amanda (650 pmt)
 $0.05 \text{ km}^3 \rightarrow \text{km}^3 = 1 \text{ Gton}$
- Funded - 1st IceCube string ✓
- 80 strings , 4800 PMT (DOMs)
+ 160x2m IceTop surface array
- Design for det.all flavor ν 's ,
from 10^7 eV (SN) to 10^{20} eV

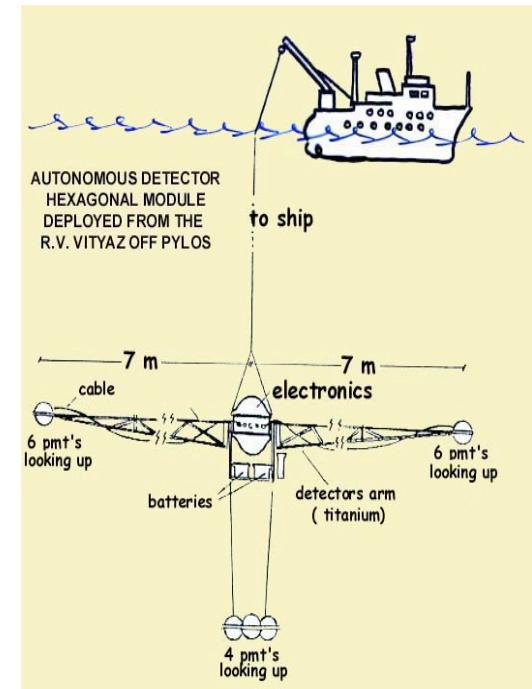


KM3NeT

- EU collaboration
- Site: Mediterranean
- Based on: **Antares, Nestor, Nemo**

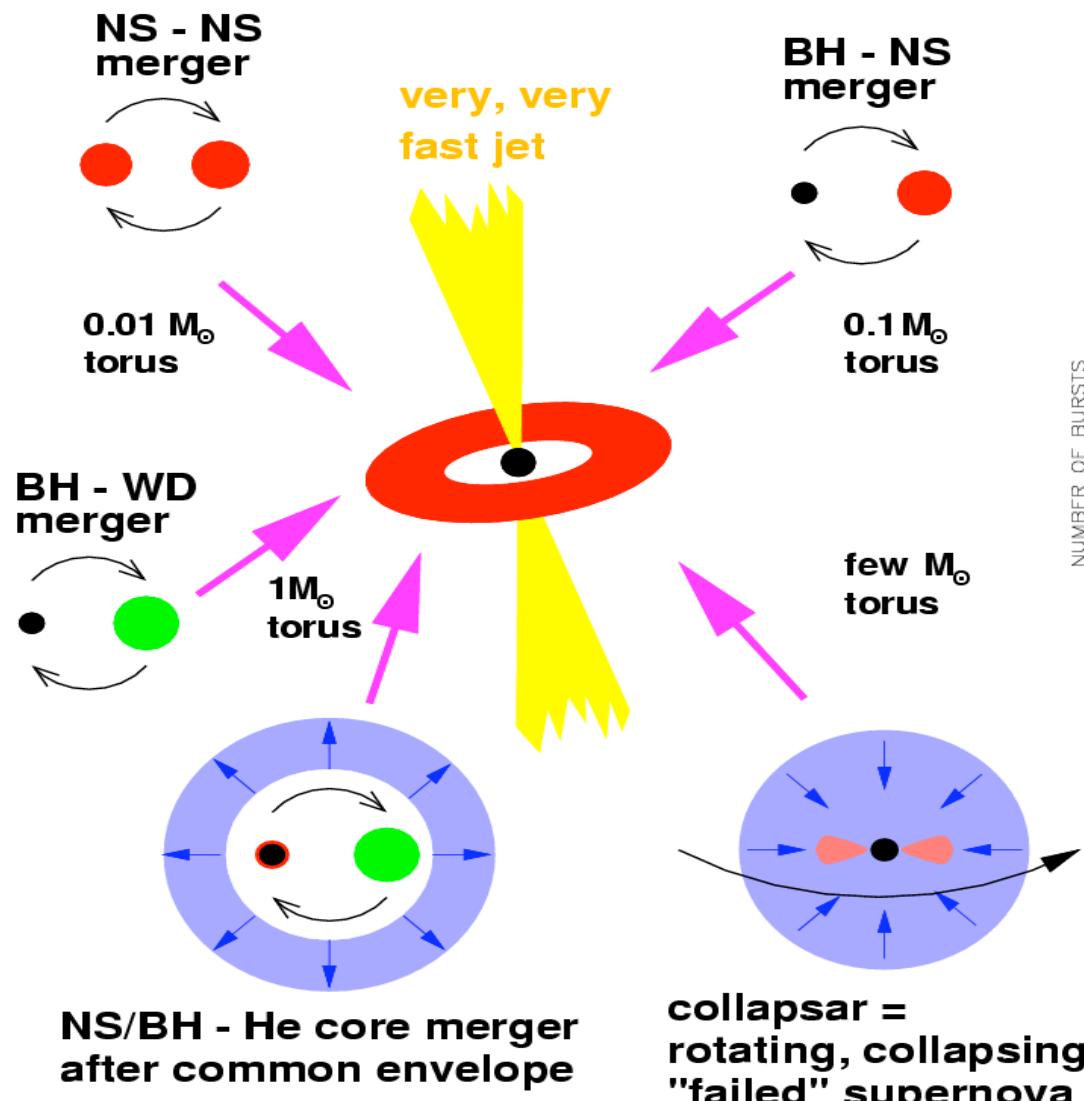


- Km³ water Cherenkov detector
- Deployment approx. 2010
- Complement ICECUBE: $\lambda_{sc,abs} \sim (100, 10) \text{ H}_2\text{O}$, $\lambda_{sc,abs} \sim (20, 100) \text{ Ice}$
- Northern site: at lower E complementary sky coverage

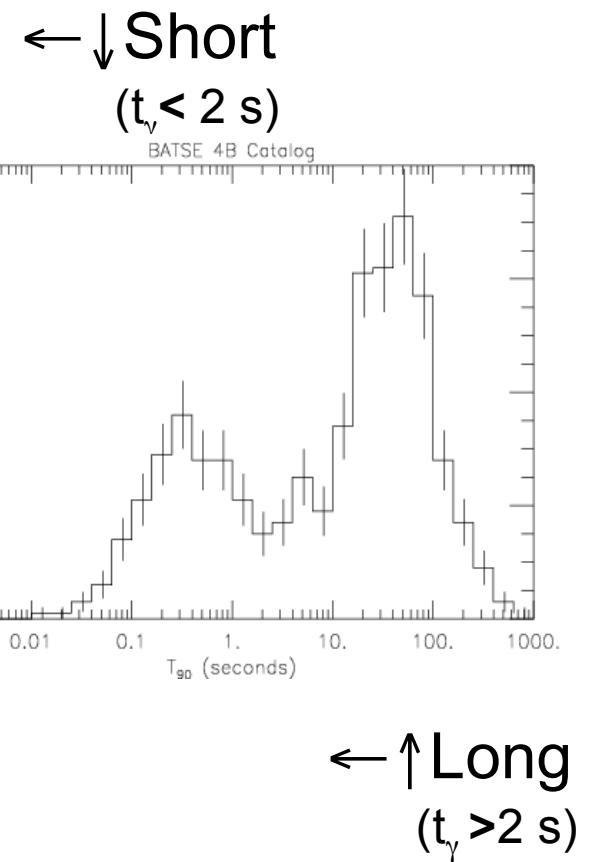


GRB: current paradigm

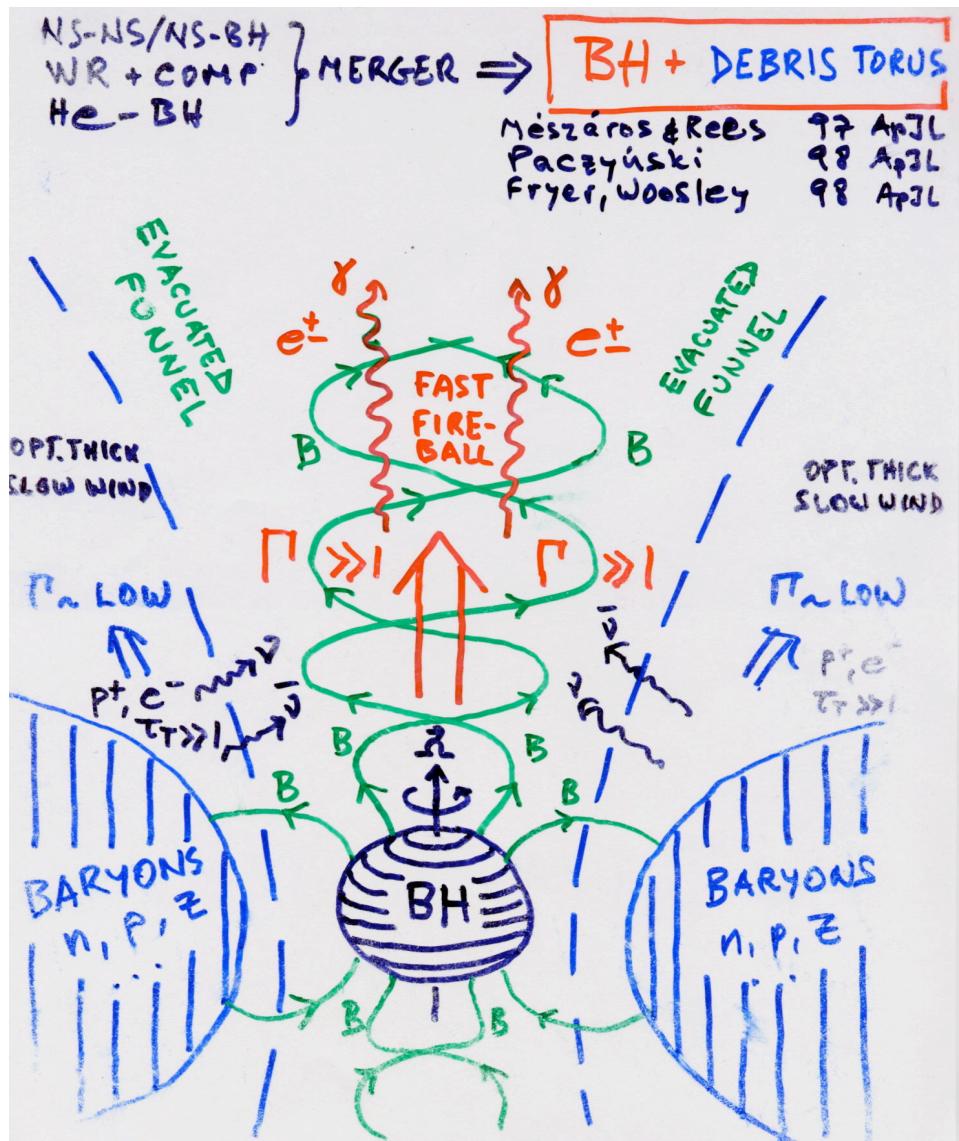
Hyperaccreting Black Holes



Bimodal distribution
of t_{γ} duration



BH + accr. Torus \rightarrow Jet



- Collapsar or merger \rightarrow BH+accr.torus
- Nuclear density hot torus $\rightarrow \nu\nu \rightarrow e^\pm$
- Hot infall \rightarrow conv.
- Dynamo $\rightarrow B \sim 10^{15}$ G, twisted (thread BH?)
- \rightarrow Alfvénic or $e^\pm p\gamma$ jet
- (Note: magnetar might do similar)

Explosion FIREBALL

- $E_\gamma \sim 10^{51} \Omega_{-2} D_{28.5}^2 F_{-5}$ erg
- $R_0 \sim c t_0 \sim 10^7 t_{-3}$ cm
 Huge energy in very small volume
- $\tau_{\gamma\gamma} \sim (E_\gamma / R_0^3 m_e c^2) \sigma_T R_0 \gg 1$
→ Fireball: e^\pm, γ, p relativistic gas
- $L_\gamma \sim E_\gamma / t_0 \gg L_{Edd} \rightarrow$ expanding ($v \sim c$) fireball

(Cavallo & Rees, 1978 MN 183:359)

- Observe $E_\gamma > 10$ GeV ...but
 $\gamma\gamma \rightarrow e^\pm$, degrade 10 GeV → 0.5 MeV?
but: threshold in CM depends on relative angle θ in Lab.,

$$E_\gamma E_t > 2(m_e c^2)^2 / (1 - \cos \theta) \sim 4(m_e c^2)^2 / \theta^2$$

Ultrarelativistic flow → $\Gamma \sim \theta^{-1} \geq 10^2$

(Fenimore et al 93; Baring & Harding 94)

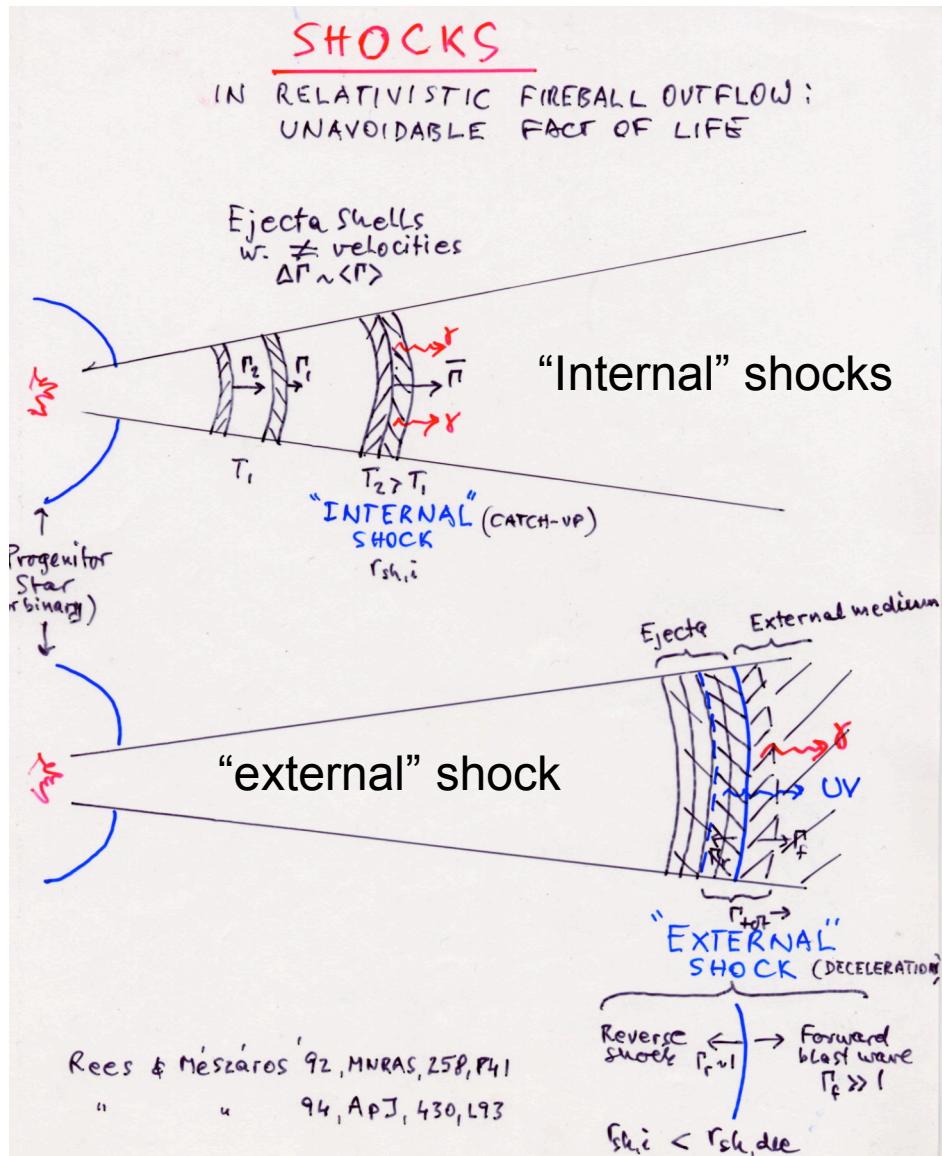


BUT:

- Why is the γ -spectrum non-thermal?
- What explains the very short (\sim ms) variability of the γ - light-curves?
- If bulk Lorentz factor $\Gamma \gg 1$, most energy is kinetic, not radiative \rightarrow inefficiency?
- **Shocks in optically thin regime outflow**

Rees & Mészáros; external shocks: 1992 MNRAS 258, 41P,
“ ” ; internal shocks, 1994, ApJ(Lett), 430, L93

Shocks in Fireball/Jet Outflow



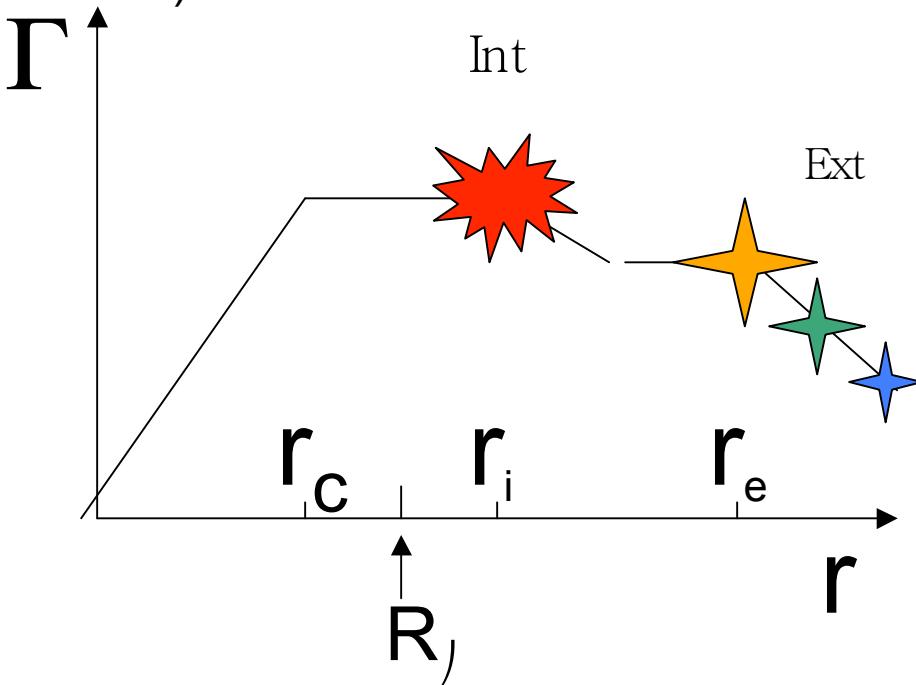
- **Shocks** expected in any unsteady supersonic outflow (esp. in a non-vacuum environment)
- **Internal** shocks: fast shells catch up slower shells (unsteady flow)
- **External** Shock: flow slows down as plows into external medium
- NOTE: “external” and “internal” shocks might be expected both while jet is **inside** star, as well as after it is **outside**. Former: γ s do not escape; latter: they do.

Internal & External Shocks

in the optically thin medium outside progenitor:

LONG-TERM BEHAVIOR?

Shocks solve radiative inefficiency problem (reconvert bulk kin. en. into random en. → radiation)

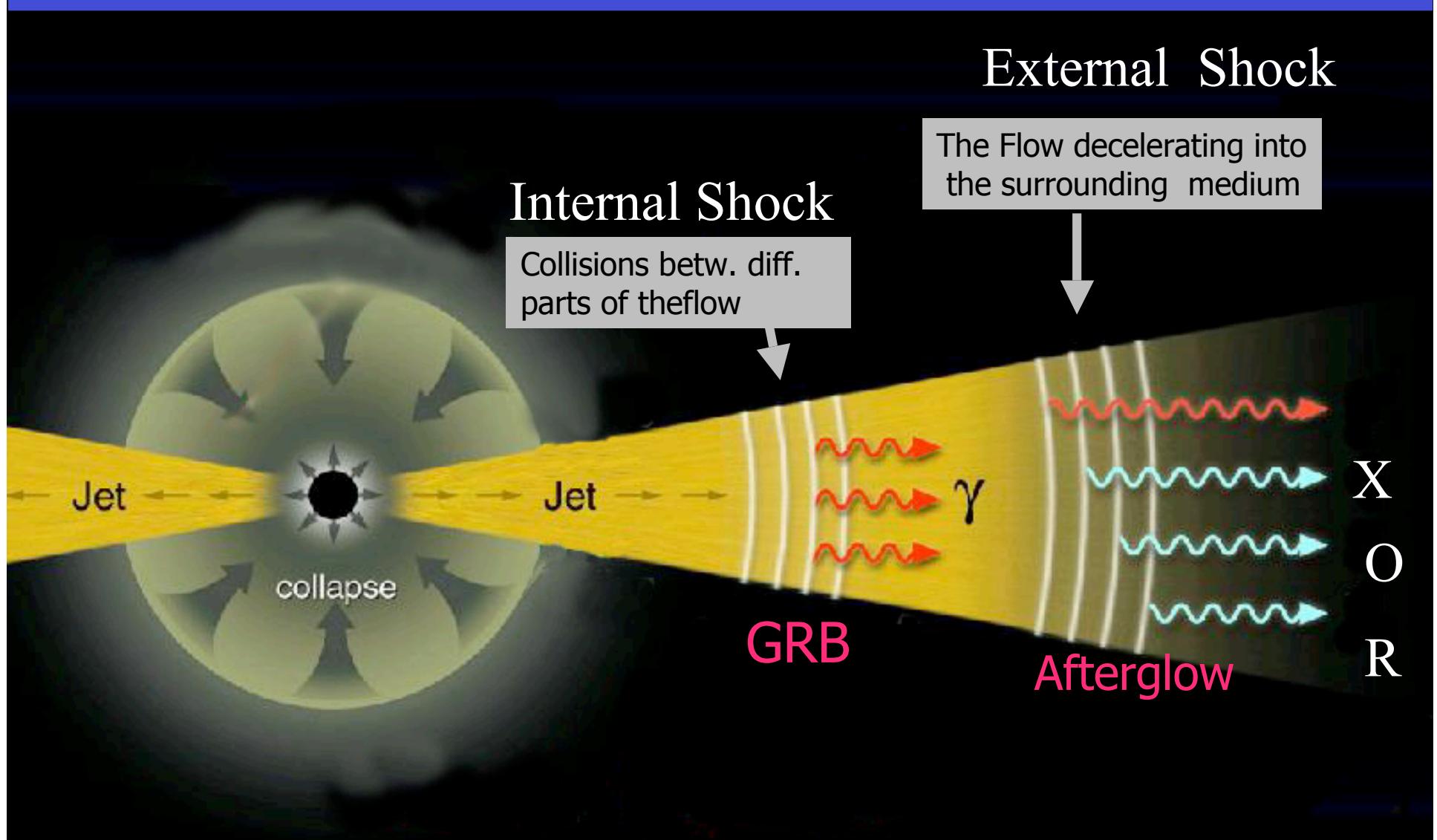


- Lorentz factor Γ first grows $\Gamma \propto r$, then coasts $\Gamma \propto \text{constant}$, until ...
- Outside the star, after jet is opt. thin:
Internal shocks: $r_i \sim 10^{12} \text{ cm}$
→ **γ-rays** (burst, t~sec)
- External shocks start at $r_e \sim 10^{16} \text{ cm}$, progressively weaken as it decelerates

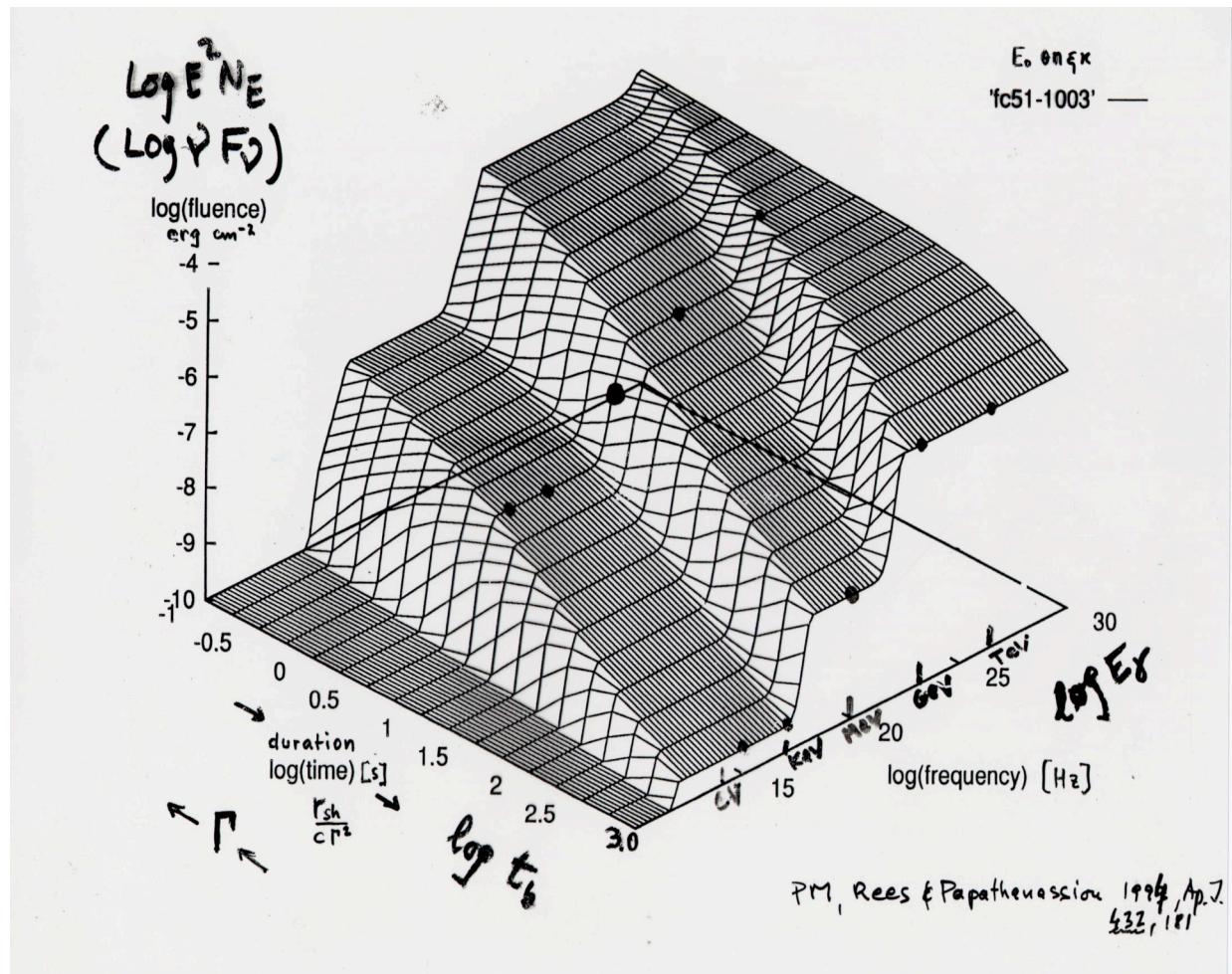
PREDICTION :

- External **forward** shock spectrum softens in time:
X-ray, optical, radio ...
→ **long fading afterglow !**
($t \sim \text{min, hr, day, month}$)
- External **reverse** shock (less relativistic):
Optical → **quick fading** ($t \sim \text{mins}$)
(Meszaros & Rees 1997 ApJ 476,232)

Fireball Model: long GRBs



External Forw. & Rev. Shock Synchrotron & IC spectrum



Lower energy
Part (eV, MeV):
Synchrotron
Higher energy

Simplest “delayed” GeV mechanism

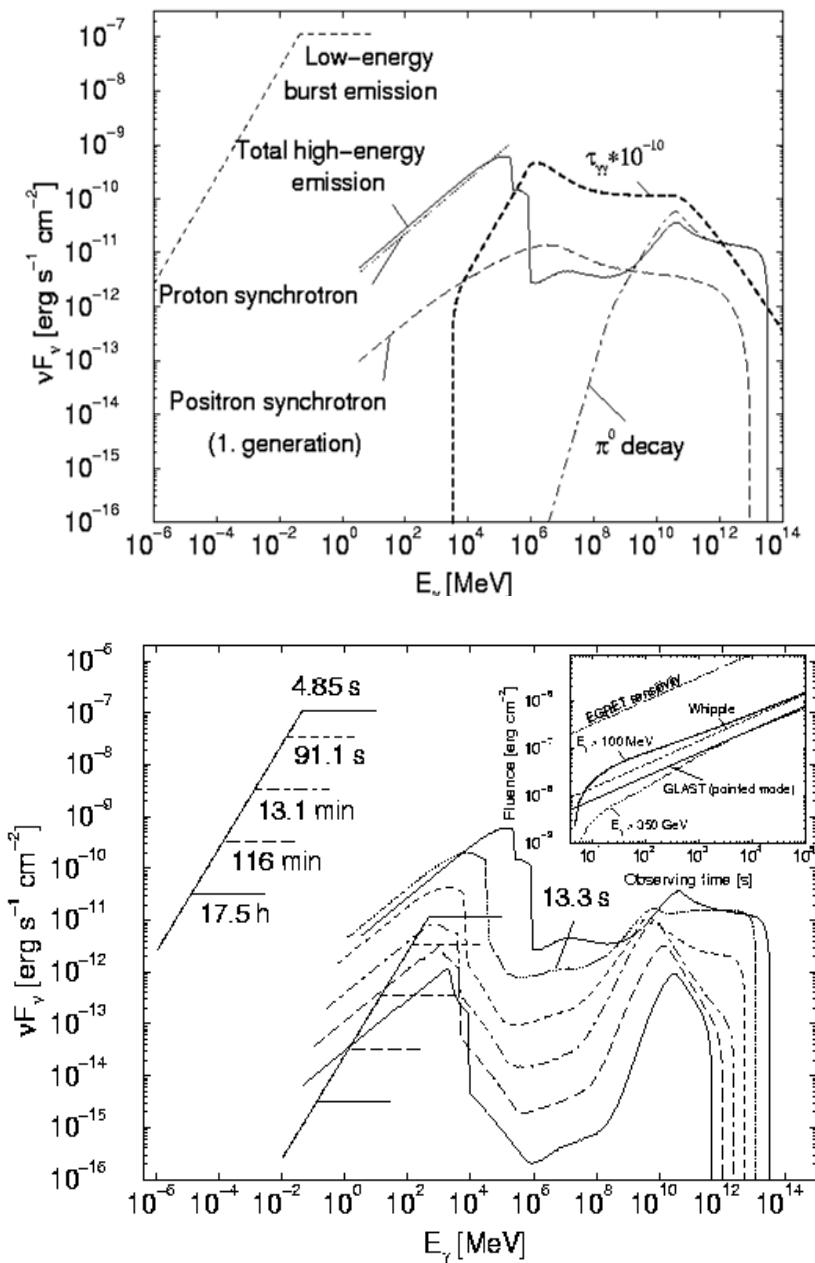
- GeV emission seen, start ~ same time as MeV trigger, but lasting ~ 1 hr:
 - could be
 - a) internal shock synchrotron
 - normal duration MeV to ~GeV
 - b) external shock (moder. Γ , low n_{ext})
 - IC → ~ GeV to TeV, lasts ~mins-hr

(Meszaros & Rees 1994 MNRAS 269, L41)

- Other possib (Katz 94) : proton impact on bin. comp.* pp → γ

GRB p γ EM cascades

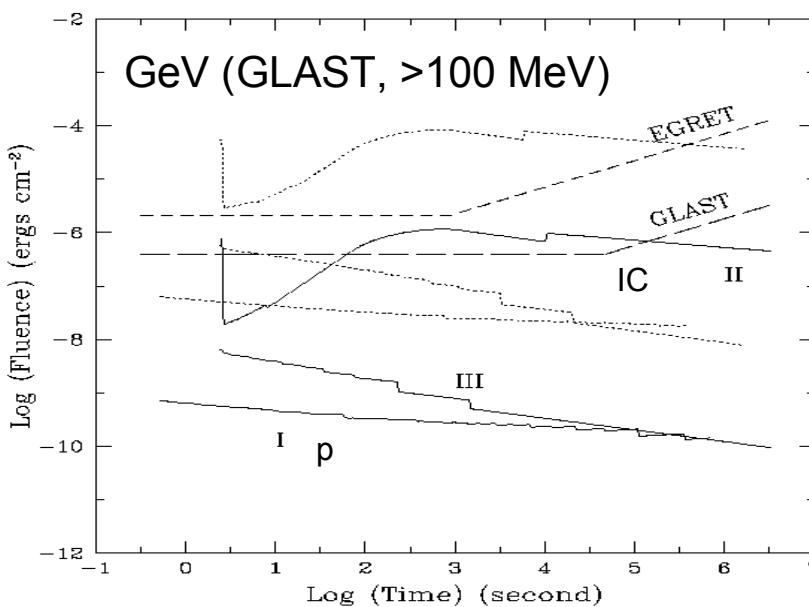
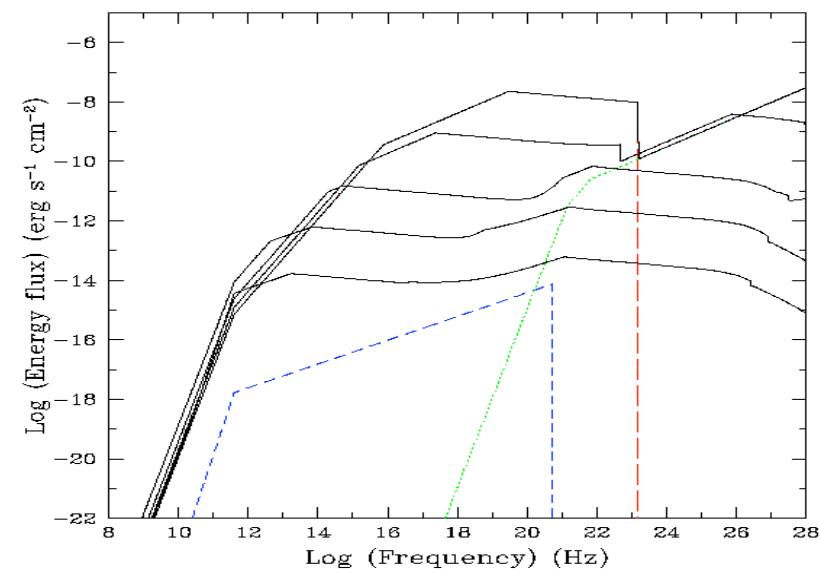
- Low energy: normalize to GRB 970508 ($z=.83$)
- Ext. forw. shock \rightarrow MeV γ s
- Proton index -2, $U_p \sim U_e$,
p-sy & p γ cascades,
 e^+ sync, π^0 dec.
- Time decay of cascade rad, slower than a'glow
decay (p's have less rad. losses)



Boettcher & Dermer 98 ApJ 499, L131 ;
Dermer, Atoyan 03, PRL 91, 1102;
Dermer, Atoyan 04, AA418, L5

GeV light-curves - IC

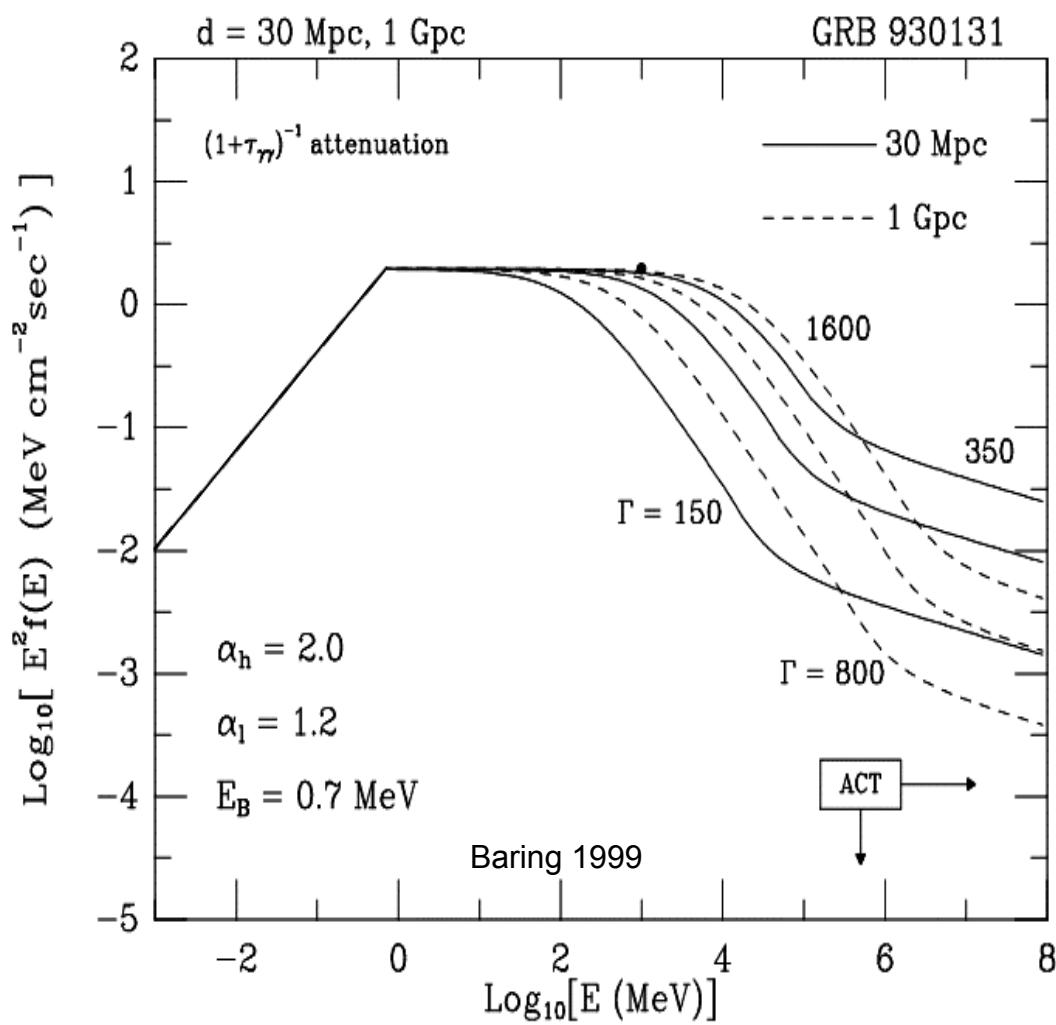
- Lightcurves start at t_{dec} , until reach $\Gamma \sim 2$.
- IC of sync. ext. shock
- Full lines: $z=1$, flat U
Dotted: $z=0.1$
- Model **IC** : recognize from **late GeV** peak 10-20 min after MeV), and from **late XR** hump (day)
- Long-dash lc: e-sy radn component
short-dash lc: p-sy($p\gamma$), radn
dotted lc : e-IC radn



Zhang & Mészáros 01 ApJ 559, 110

Mészáros pan05

GeV-TeV photons from GRB



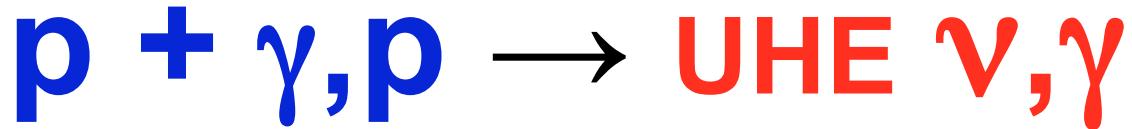
- Internal shocks: $\gamma\gamma \rightarrow e^\pm$, $\tau_{\gamma\gamma} \geq 1$ @ $E_\gamma \sim \Gamma^2$ GeV
→ pair cutoff in spectr
→ get info about r_{sh} (compactness, $\tau_{\gamma\gamma}$)
- In ext.shock, $\tau_{\gamma\gamma} \leq 1$ on GRB target γ ;
- test if shock is int. or ext;
test bulk Lorentz factor,
shock accel efficiency,
magnetic field in shock
(max. e^\pm energy? → size
of accel region)

Γ_{\max} upper limits in sel. GRB

Lithwick & Sari 01 ApJ 555,540 :

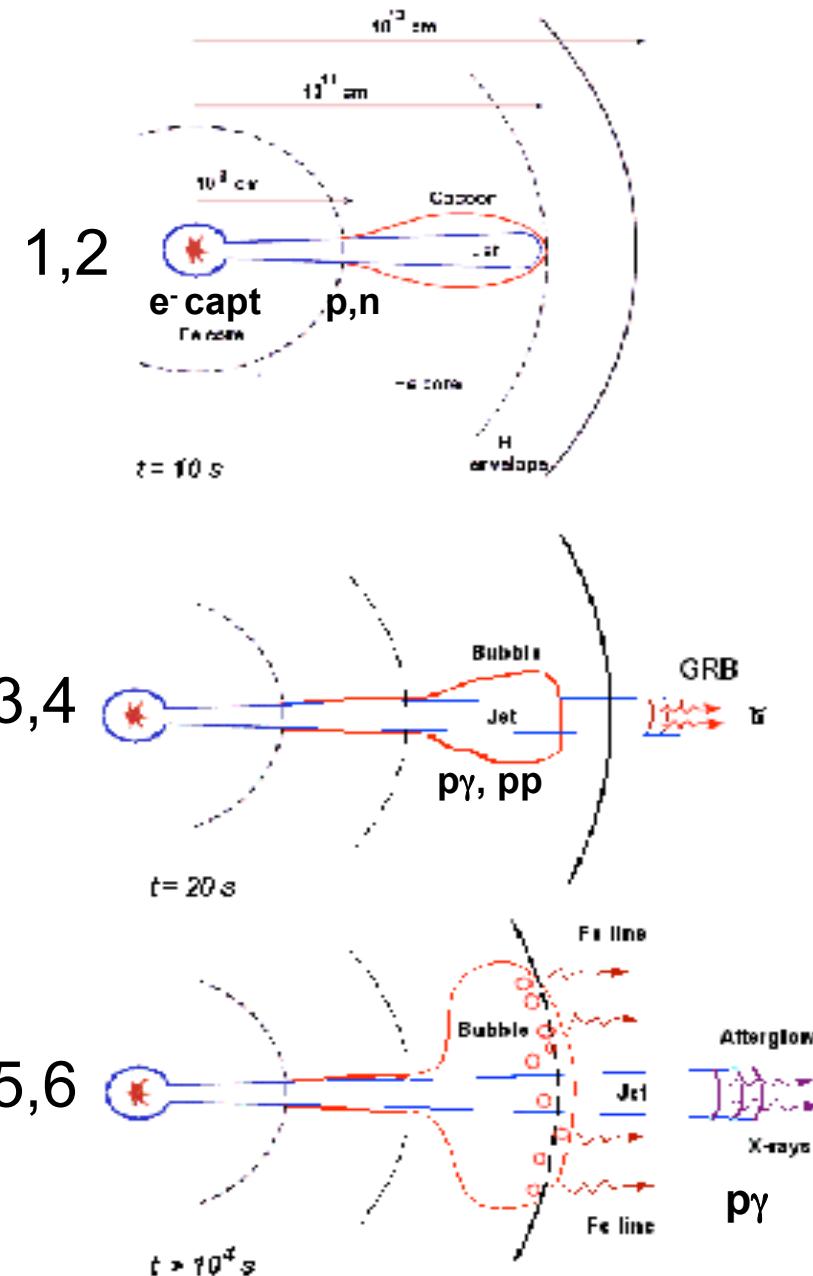
Use Γ -dependence of comoving photon density which determines max. escaping photon energy

	$E_m/m_e c^2$	z	Γ_{m1}	Γ_{m2}
910503	333	1	340	300
910601	9.8	1	72	110
910814	117	1	200	190
930131	1957	1	420	270
940217	6614	1	340	120
950425	235	1	300	280
990123	37	1.6	150	180
971214*	1	3.42	192	410
980703*	1	.966	69	140
990510*	1	1.62	98	200



- If protons present in (baryonic) jet $\rightarrow p^+$ Fermi accelerated (as are e^-)
- $p, \gamma \rightarrow \pi^\pm \rightarrow \mu^\pm, \nu_\mu \rightarrow e^\pm, \nu_e, \nu_\mu$ (Δ -res.: $E_p E_\gamma \sim 0.3 \text{ GeV}^2$ in jet frame)
 $\rightarrow E_{\nu, \text{br}} \sim 10^{14} \text{ eV}$ for MeV γ s (int. shock)
 $\rightarrow E_{\nu, \text{br}} \sim 10^{18} \text{ eV}$ for 100 eV γ s (ext. rev. sh.) : **ICECUBE**
- $\rightarrow \pi^0 \rightarrow 2\gamma \rightarrow \gamma\gamma$ cascade : **GLAST, ACTs..**
(Waxman-Bahcall 1997;99; Boettcher-Dermer 1998; 00;)
- Test hadronic content of jets (are they pure MHD/ e^\pm , or baryonic ...?)
- Test acceleration physics (injection effic., ϵ_e, ϵ_B ..)
- Test scattering length (magnetic inhomog. scale?..or non-Fermi?..)
- Test shock radius: $\gamma\gamma$ cascade cut-off:
 $\epsilon_\gamma \sim \text{GeV (internal shock)} ; \epsilon_\gamma \sim \text{TeV (ext shock/IGM)}$
 \rightarrow photon cut-off: diagnostic for int. vs. ext-rev shock

UHE ν in GRB

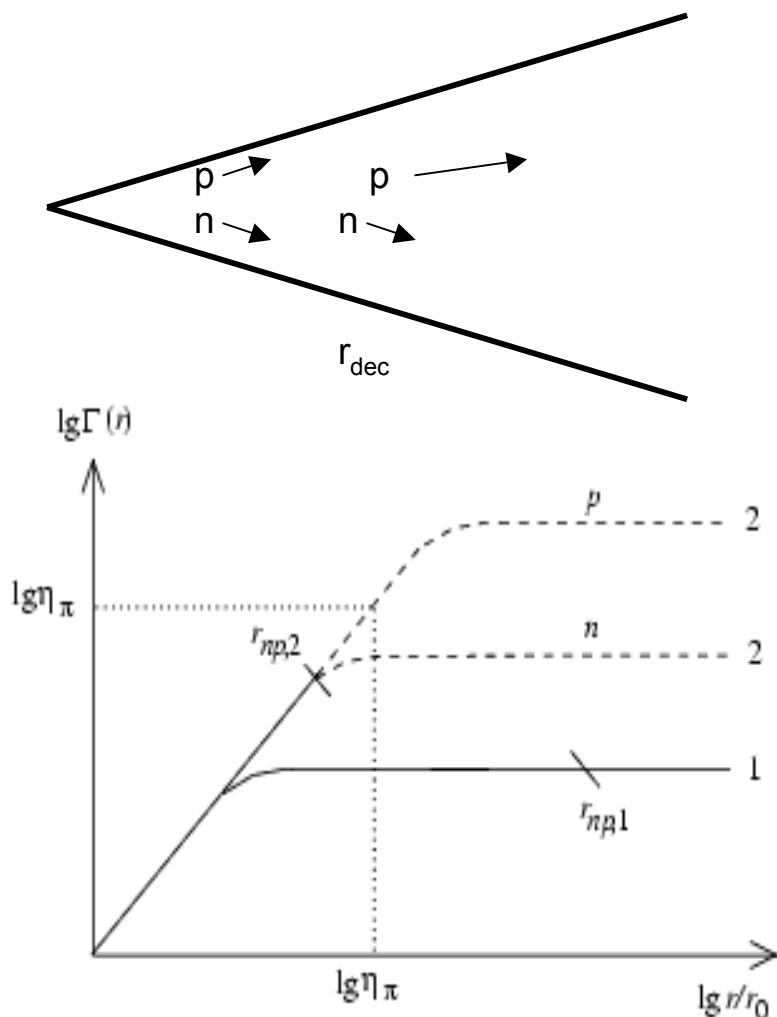


6 possible collapsar GRB ν -sites

- 1) at collapse, make GW + **thermal vs (MeV)**
- 2) If jet outflow is baryonic, have p,n
→ p,n relative drift, **pp/pn** collisions
→ inelastic nuclear collisions
→ **VHE ν (GeV)**
- 3) Int. shocks while jet is inside / can accel. protons → **p γ , pp/pn** collisions
→ **UHE ν (TeV)**
- 4) Int. shocks outside / accel. protons
→ **p γ** collisions → **UHE ν (100 TeV)**
- 5) ← Ext. rev. shock → **EeV ν (10^{18} eV)**
- 6) **If** supranova shell present outside
(SN occurred >2 days before GRB?)
→ **p γ , pp** of jet protons on shell targets
→ **UHE ν (> TeV) [..now constrained]**

“Hadronic” GRB Fireballs:

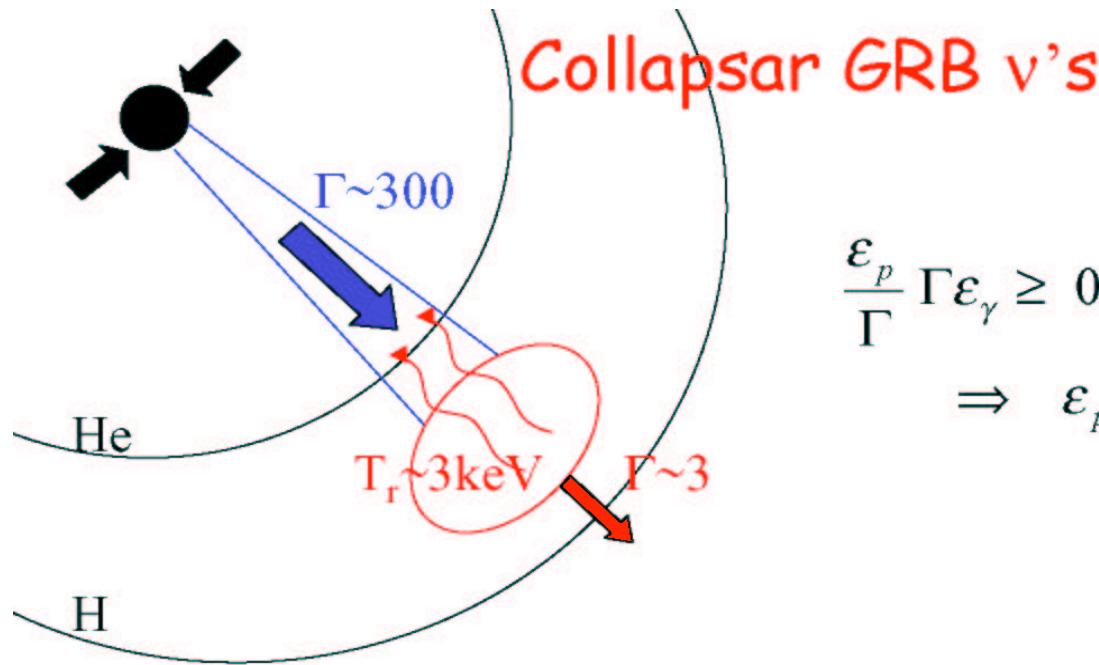
Thermal p,n decoupling \rightarrow VHE ν, γ



- p,n in fireball move together while $t_{pn} < t_{exp}$ (rad. acts on p, elastic scatt. couples p,n)
- p,n decouple when $t_{pn} > t_{exp}$, where $\tau_{pn} \sim 1$, $v_{rel} \rightarrow c$, $\sigma_{pn} \rightarrow$ inelastic; this occurs for $\Gamma > \Gamma_\pi \sim 400$
(Derishev et al 99; Bahcall,Meszaros 00; Fuller et al 00)
- Inelastic pn $\rightarrow \pi^\pm \rightarrow \mu^\pm, \nu_\mu \rightarrow e^\pm, \nu_e, \nu_\mu$
 $\rightarrow \pi^0 \rightarrow 2\gamma$
- ν_μ : $\epsilon_{\nu_\mu} \sim 5-10 \text{ GeV} \rightarrow \text{ICECUBE?}$
det @ $z \sim 1$, $R_\nu \sim 7/\text{yr}$ from all GRB,
but only if larger PMT density
- γ -rays: $\pi^0 \rightarrow 2\gamma$, $\rightarrow \text{GLAST}$,
 $\epsilon_\gamma \sim 10 \text{ GeV}$, detect @ $z < 0.1$

(Bahcall & Meszaros 2000 PRL 85:1362); Lemoine 2002; Beloborodov, 2002

While jet is inside progenitor:



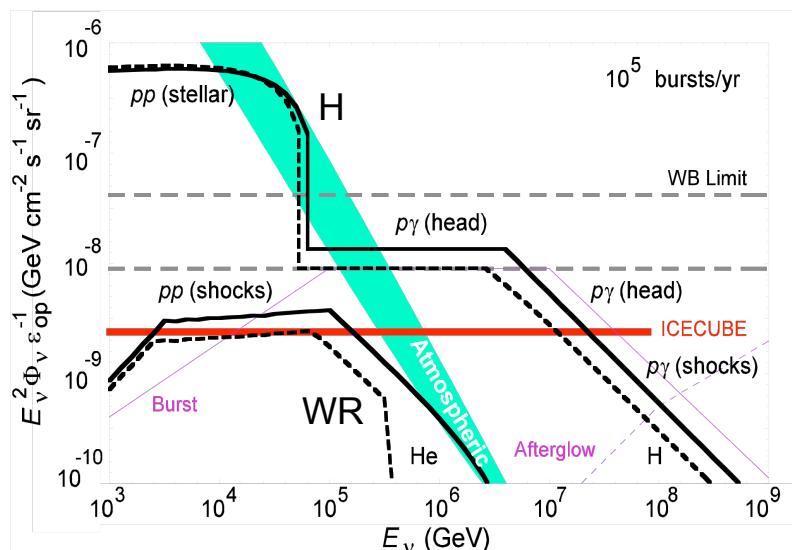
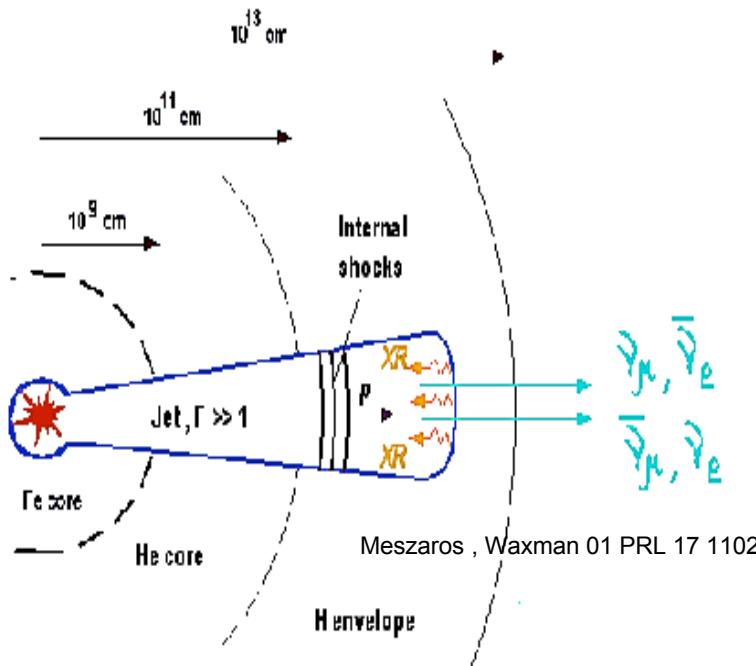
$$\frac{\epsilon_p}{\Gamma} \Gamma \epsilon_\gamma \geq 0.3 \text{ GeV}^2$$
$$\Rightarrow \epsilon_p \geq 100 \text{ TeV}$$

- $\epsilon_\nu \geq 10^{12.5} \text{ eV}$
- $N_{\nu \rightarrow \mu} \approx 0.2 / \text{km}^2 / \text{Collapse} \quad (10^3 \text{ GRBs/yr})$

- Both "Chocked" and "successful" jets

Meszaros & Waxman 01

(2) Jet inside star: GRB ν, γ Precursor

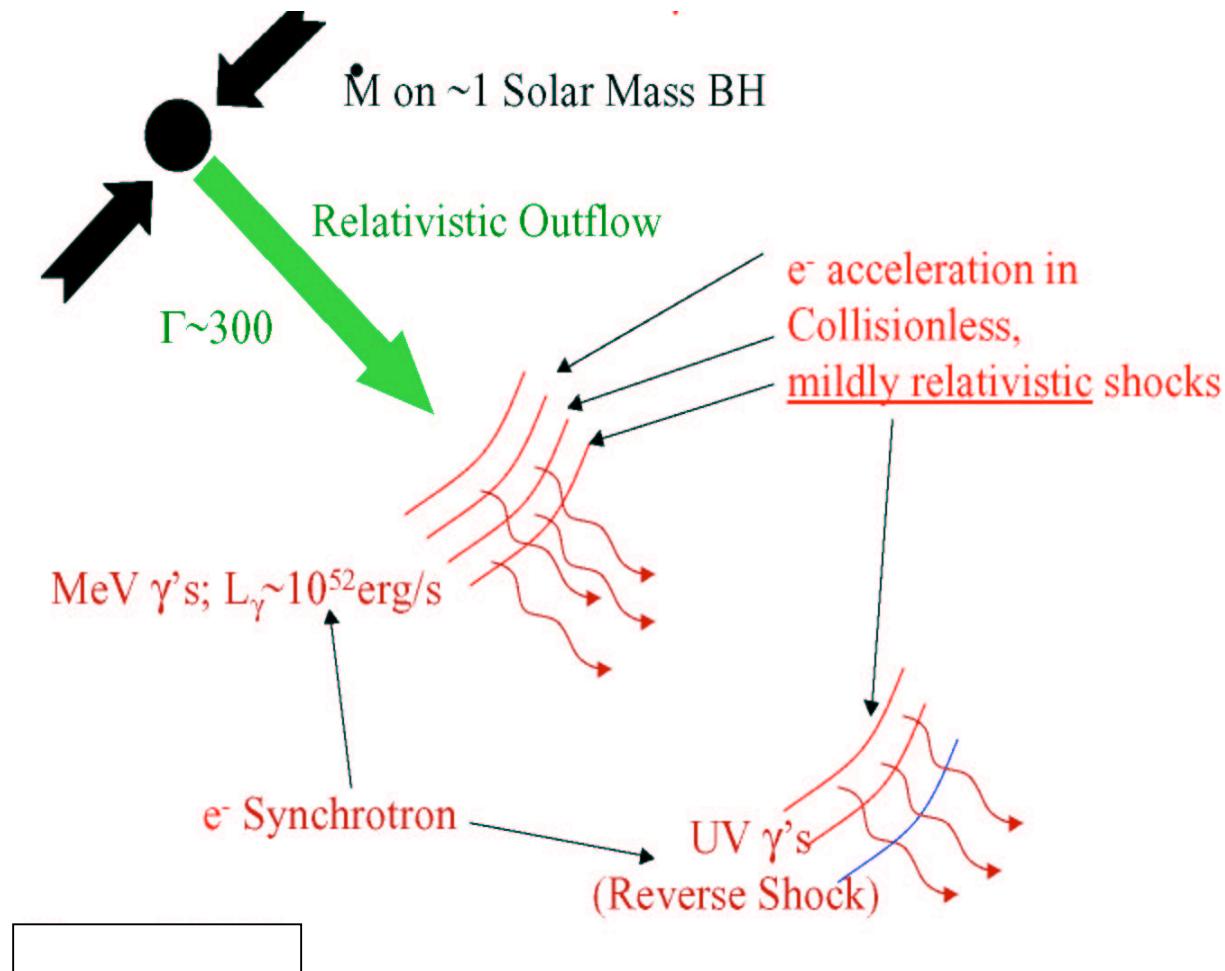


Razzaque, Mészáros, Waxman 03 PRD 68, 3001)

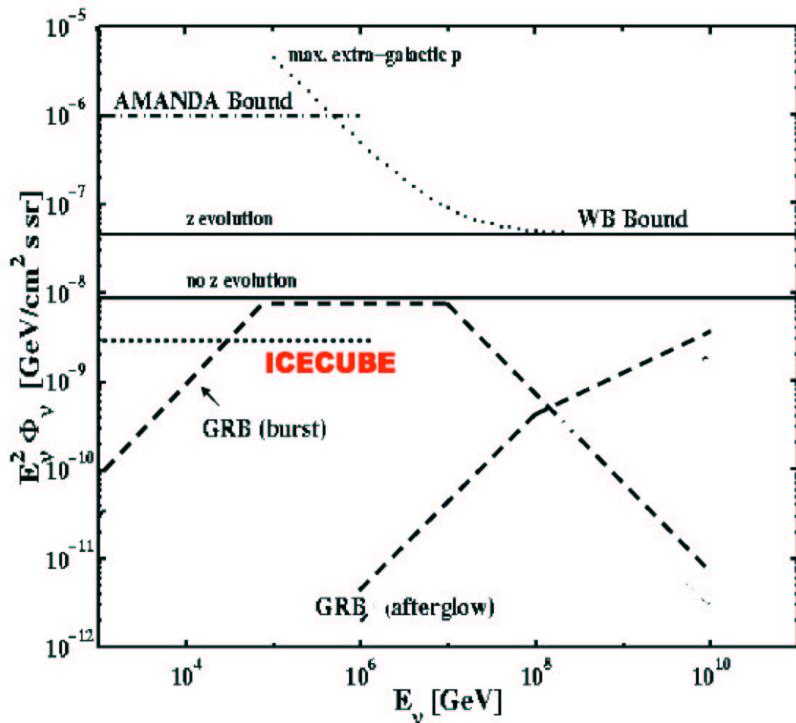
- Jet propagating through progenitor, **BEFORE** emerging from stellar envelope, can have int. shocks which accel. $p^+ \rightarrow p\gamma$ on unobserved X-rays , $\rightarrow \pi^\pm, \nu$
 pp, pn on stellar envelope $\rightarrow \pi^\pm, \nu$
 - **few TeV neutrino precursor**
- If progenitor has H-layer $R_j \sim 10^{12}$ cm (BSG) → Rate(ν_μ, TeV) prec > Rate($\nu_\mu, 100 \text{ TeV}$) int.shock
(easier to detect in **ICECUBE**)
- but, if WR (He core), $R_j \sim 10^{11}$ cm → Rate(ν_μ, TeV) prec < Rate($\nu_\mu, 100 \text{ TeV}$) int.shock
→ **test progen. size** (e.g. @ high z : popIII?)
- If jet **DOES NOT** escape ⇒ “choked” jet, vs escape, γs don’t → **“hidden ν source”**
- If jet **break-out**: → photon flashes
 - **Blue ν-spectrum: ~100 TeV**
 - **$p, \gamma \rightarrow \nu$ from shocks outside star**

Mészáros pan05

When jet is outside progenitor star: GRB internal & external shocks



νs from pγ in internal & external shocks in GRB

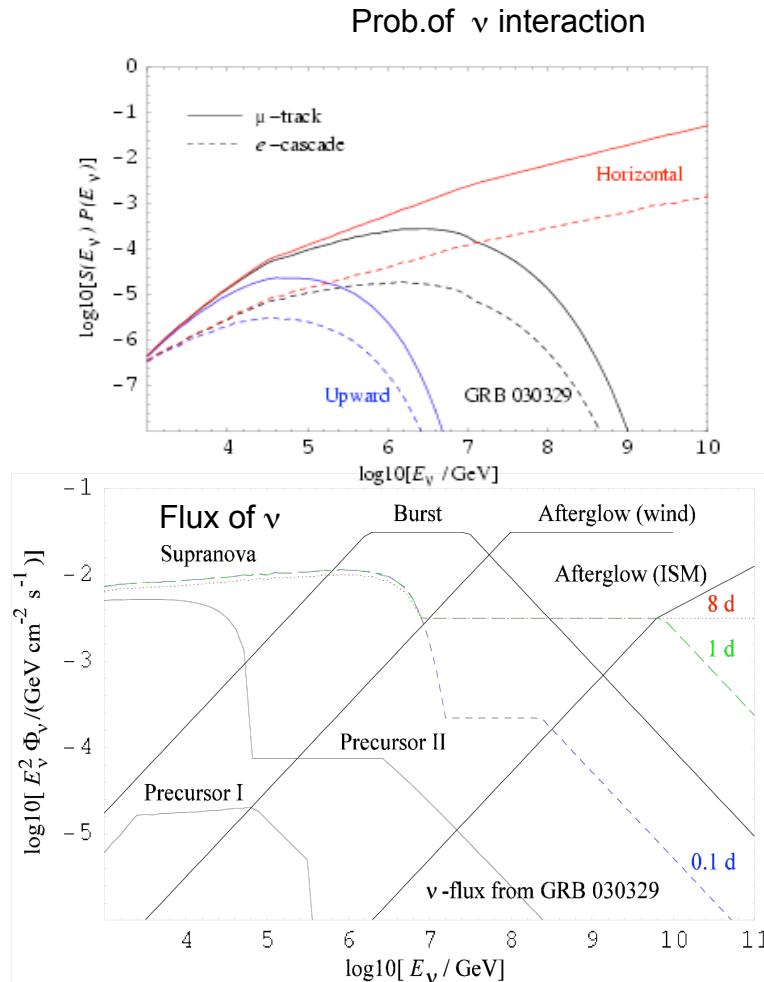


Waxman, Bahcall 97 PRL

- Shocks accelerate p^+ (as well as the e^- which produce γ_{MeV})
- Δ -res.: $E'_p E'_\gamma \sim 0.3 \text{ GeV}^2$ in comoving frame, in lab:
 $\rightarrow E_p \geq 3 \times 10^6 \Gamma_2^2 \text{ GeV}$
 $\rightarrow E_\nu \geq 1.5 \times 10^2 \Gamma_2^2 \text{ TeV}$
- Internal shock p, γ_{MeV}
 $\rightarrow \sim 100 \text{ TeV}$ vs
- External shock p, γ_{UV}
 $\rightarrow \sim 0.1-1 \text{ EeV}$ vs
- Diffuse flux: detect in km^3

GRB 030329: precursor (& pre-SN shell?) with ICECUBE

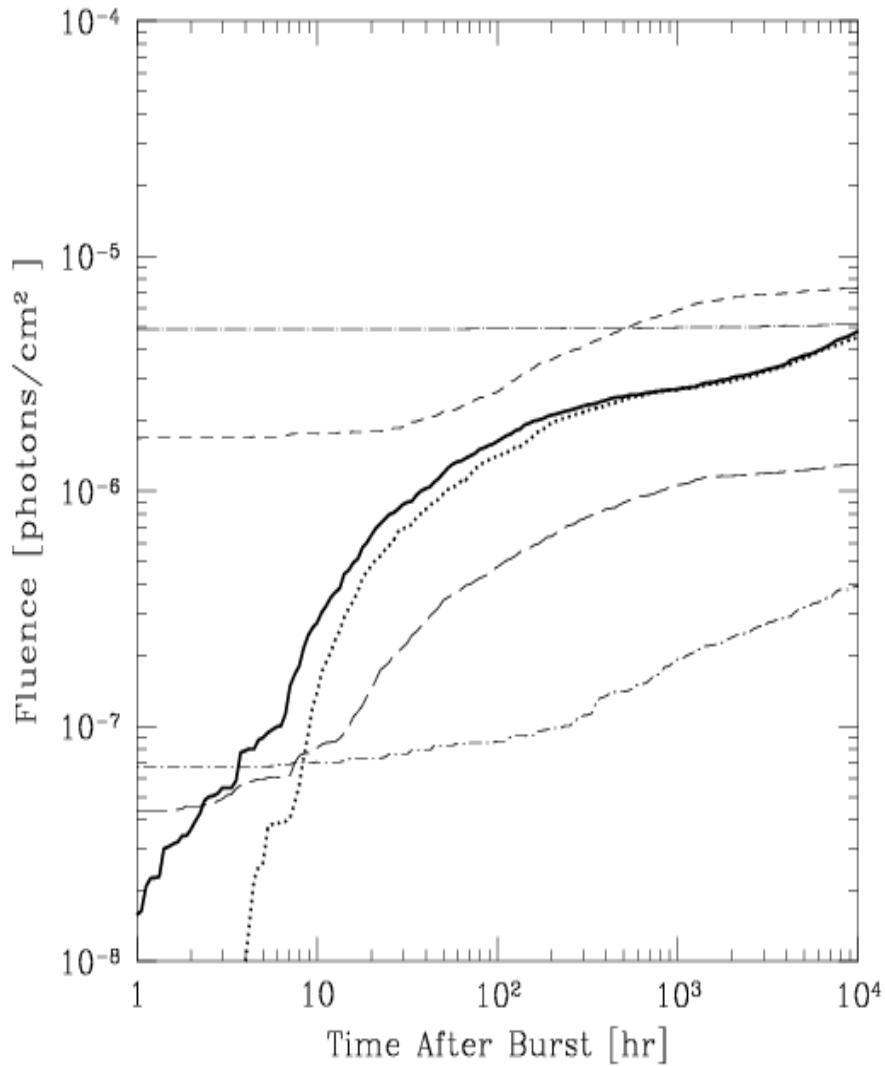
Burst of $L_{\gamma} \sim 10^{51}$ erg/s, $E_{SN} \sim 10^{52.5}$ erg, @ $z \sim 0.17$, $\theta \sim 68^\circ$



Flux Component	TeV-PeV		PeV-EeV	
	μ -track	e-cascade	μ track	e-cascade
Precursor I	$9 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	-	-
	$6 \cdot 10^{-3} \uparrow$	$2 \cdot 10^{-3} \uparrow$	-	-
	$0.01 \rightarrow$	$2 \cdot 10^{-3} \rightarrow$	-	-
Precursor II	4.1	1.1	$3 \cdot 10^{-3}$	$2 \cdot 10^{-4}$
	$2.9 \uparrow$	$0.9 \uparrow$	-	-
	$4.4 \rightarrow$	$1.2 \rightarrow$	$0.01 \rightarrow$	$8 \cdot 10^{-4} \rightarrow$
Burst	1.8	0.2	1.4	0.1
	$0.3 \uparrow$	$0.04 \uparrow$	-	-
	$2.9 \rightarrow$	$0.3 \rightarrow$	$7.6 \rightarrow$	$0.4 \rightarrow$
Afterglow (ISM)	$2 \cdot 10^{-4}$	$2 \cdot 10^{-5}$	$2 \cdot 10^{-4}$	$1 \cdot 10^{-5}$
	$3 \cdot 10^{-5} \uparrow$	$4 \cdot 10^{-6} \uparrow$	-	-
	$2 \cdot 10^{-4} \rightarrow$	$2 \cdot 10^{-5} \rightarrow$	$0.01 \rightarrow$	$5 \cdot 10^{-4} \rightarrow$
Afterglow (wind)	0.03	$3 \cdot 10^{-3}$	0.05	$3 \cdot 10^{-3}$
	$5 \cdot 10^{-3} \uparrow$	$7 \cdot 10^{-4} \uparrow$	-	-
	$0.05 \rightarrow$	$5 \cdot 10^{-3} \rightarrow$	$1.4 \rightarrow$	$0.06 \rightarrow$
Supernova 0.1 d	12.4	2.4	0.5	0.03
	$6.1 \uparrow$	$1.6 \uparrow$	-	-
	$14.9 \rightarrow$	$2.7 \rightarrow$	$1.6 \rightarrow$	$0.1 \rightarrow$
Supernova 1 d	12.4	2.4	0.5	0.03
	$6.1 \uparrow$	$1.6 \uparrow$	-	-
	$14.9 \rightarrow$	$2.7 \rightarrow$	$1.9 \rightarrow$	$0.1 \rightarrow$
Supernova 8 d	10.9	2.2	0.4	0.03
	$5.4 \uparrow$	$1.4 \uparrow$	-	-
	$13.2 \rightarrow$	$2.4 \rightarrow$	$1.7 \rightarrow$	$0.1 \rightarrow$

Razzaque, Mészáros, Waxman 03 PRD 69, 23001

Mészáros pan05



Fluence of $> 1 \text{ TeV} \gamma$ from $E=10^{51} \text{ erg}$ GRB at 100 Mpc
In patchy IGM (80% voids w. $B \sim 10^{-15} \text{ G}$, 20% $B \sim 10^{-11} \text{ G}$;
TeV Fluence $\sim 2\%$ of energy in GZK protons

TeV secondary γ from UHE p

- GRB can accelerate p to $E_p \sim 10^{20} \text{ eV}$
- Cascades on bkg CMB & IR $\gamma \rightarrow e^\pm$
- $e^\pm, \gamma_{\text{cmb,ir}} \rightarrow e^\pm, \gamma_{\text{TeV}}$
- Delay: p, e^\pm in B_{igm}
 $\rightarrow 0.1\text{-}1 \text{ TeV} \gamma$ from
 $d < 100 \text{ Mpc}$ in $\Delta t \sim dy$
(Waxman & Coppi 96, ApJL (/9603144))
- More detailed calculation: Dermer, 02 ApJ,

Delayed Secondary GeV γ -rays from GRB

- TeV γ -rays from GRB shocks pair-produce on IR bkg γ 's, and e^\pm IC upscatter CMB γ 's,
 \rightarrow 60-800 MeV secondary γ
 $\Delta t \sim 10^3$ s delayed (max[t _{$\gamma\gamma$} , t_{IC}] obs frame),

(Dai, Lu '02, ApJL , a-ph/0203084)

Collapsar & SN connection

- Core collapse of star w. $M \sim 30 M_{\text{sun}}$
 - BH + disk (if fast rot.core)
 - jet (MHD? baryonic? high Γ ,
+ SNR envelope eject (?)
- 3D hydro simulations (Newtonian
SR) show that baryonic jet w.
high Γ can be formed/escape
- SNR: not seen *numerically* yet
(but: several previous observ.
suggestions, e.g. late I.c. hump +
reddening) ;
... and more recently
...

GRB030329/SN2003dh

Credit: Derek Fox & NASA ↓

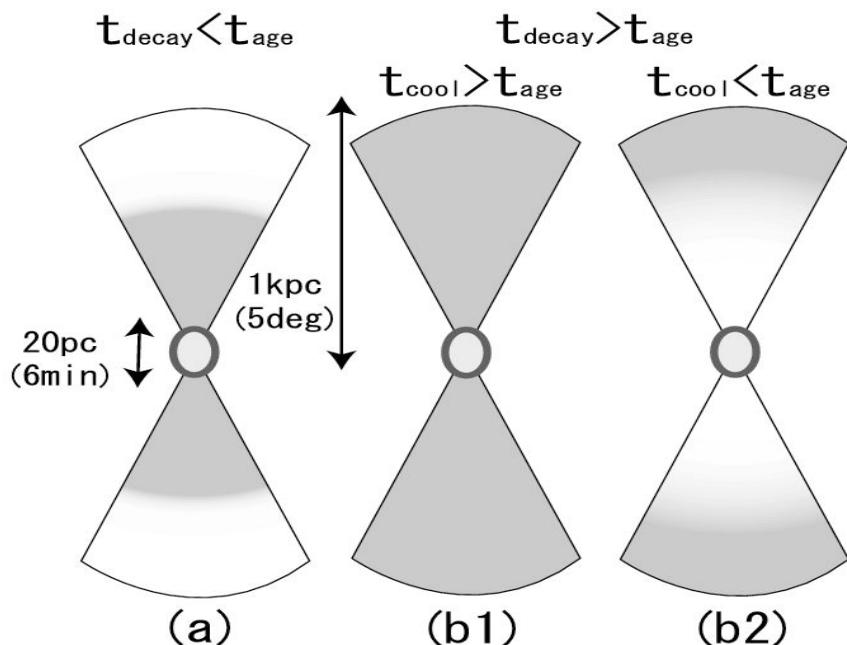


Mészáros pan05



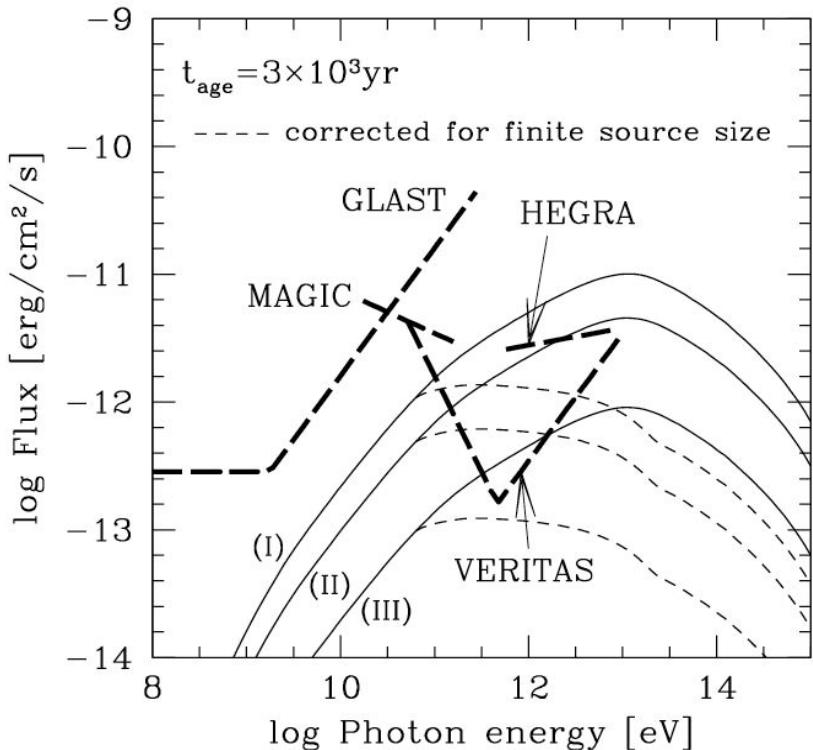
W49B: a GRB remnant?

← CXC/Spitzer obs: two jets, rich in Fe
(~ GRB remnant) (Clavin, Roy, Watzke '04)



- ~3000 yr old: **any UHE signature?**
 - Paradigm: GRB as CR accelerator
→ cosmic ray n escaped the ejecta
(uncharged), later decay
 - β decay $e^- \rightarrow$ synchrotron + IC in B_{gal}
and CMB → **GeV-TeV γ**
 - Geometry depends on ratio of
 t_{dec} , t_{cool} and t_{age}
- (Ioka, Kobayashi, Mészáros 04 ApJ 613, L17)

W49 as a smouldering GRB CR accelerator

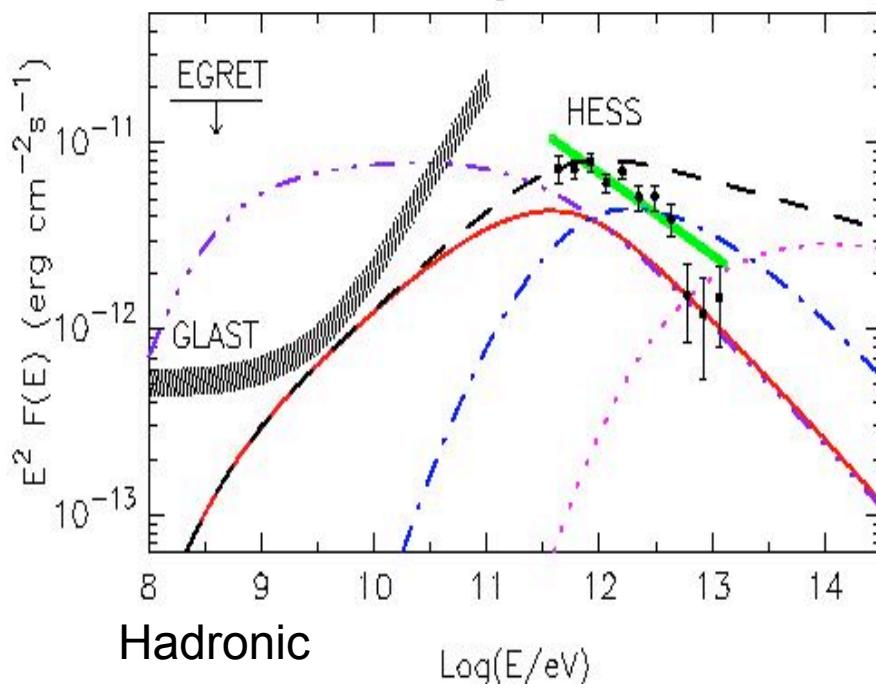
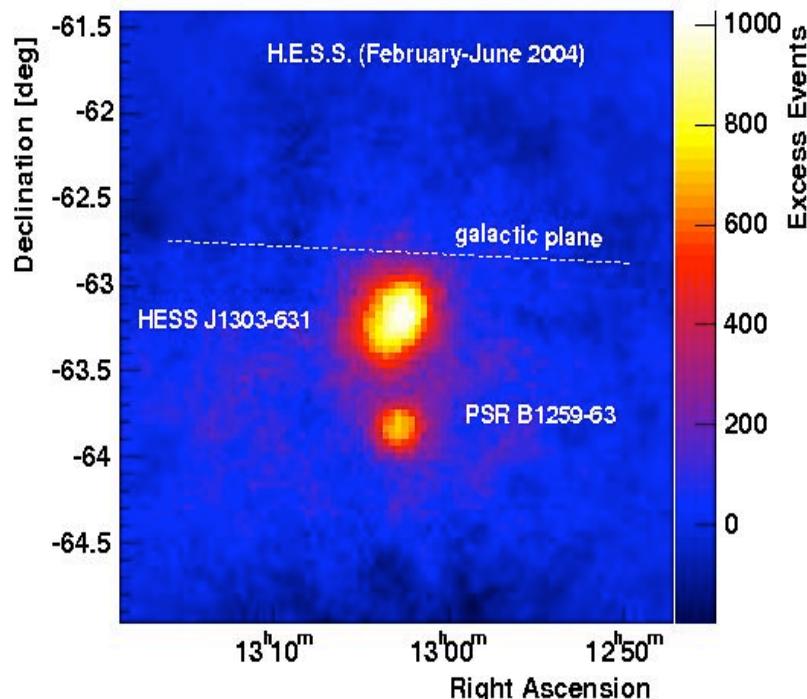


- $\varepsilon_{\text{ic,cmb}} \sim 50 \text{ TeV}$
- Depending on n / CR flux normalization rel. to GRB,
 $\varepsilon F_\varepsilon \sim 10^{-11} \text{ erg/s/cm}^2$
 $\varepsilon F_\varepsilon / \Omega \sim 5 \cdot 10^{-9} \text{ erg/s/cm}^2/\text{sr} \rightarrow$ possibly detectable w.

VERITAS, MAGIC, HEGRA

(northern location → not observable with
HESS, CANGAROO)

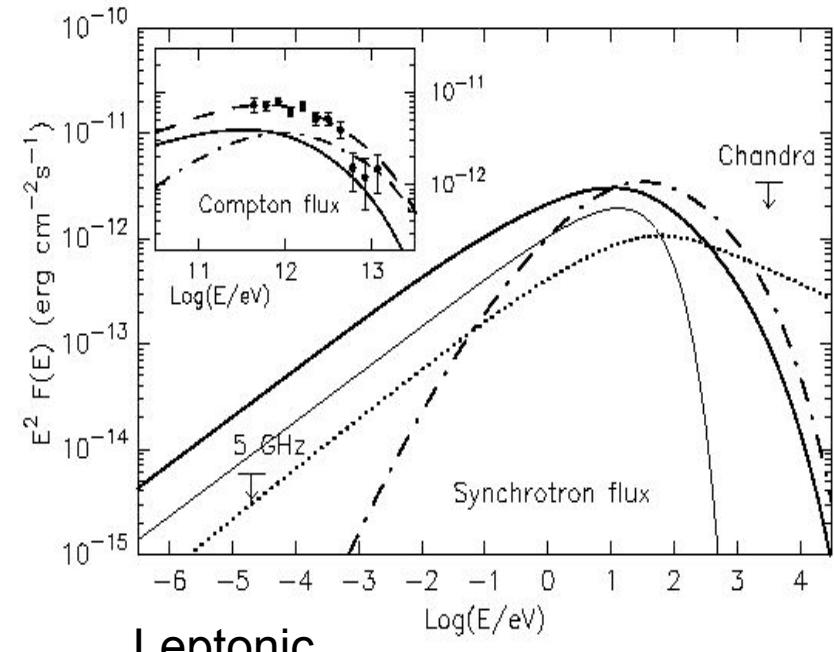
Note: neutrons escape remnant, imaging
permits distinguishing n-decay outside
source from possible π^0 decay following
proton acceleration in the SNR shock



Un-ID TeV source: HESS J1303-631 a GRB remnant?

Emission absent at energies < TeV . Possibly GRBR at d=12 kpc, t=15,000 yr, $n_H=1 \text{ cm}^{-3}$

Atoyan, Buckley, Krawczynski, astro-ph/0509615

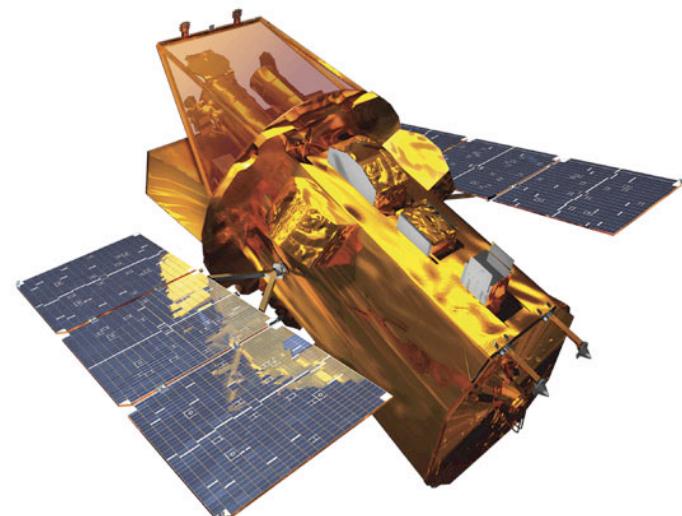


Mészáros pan05



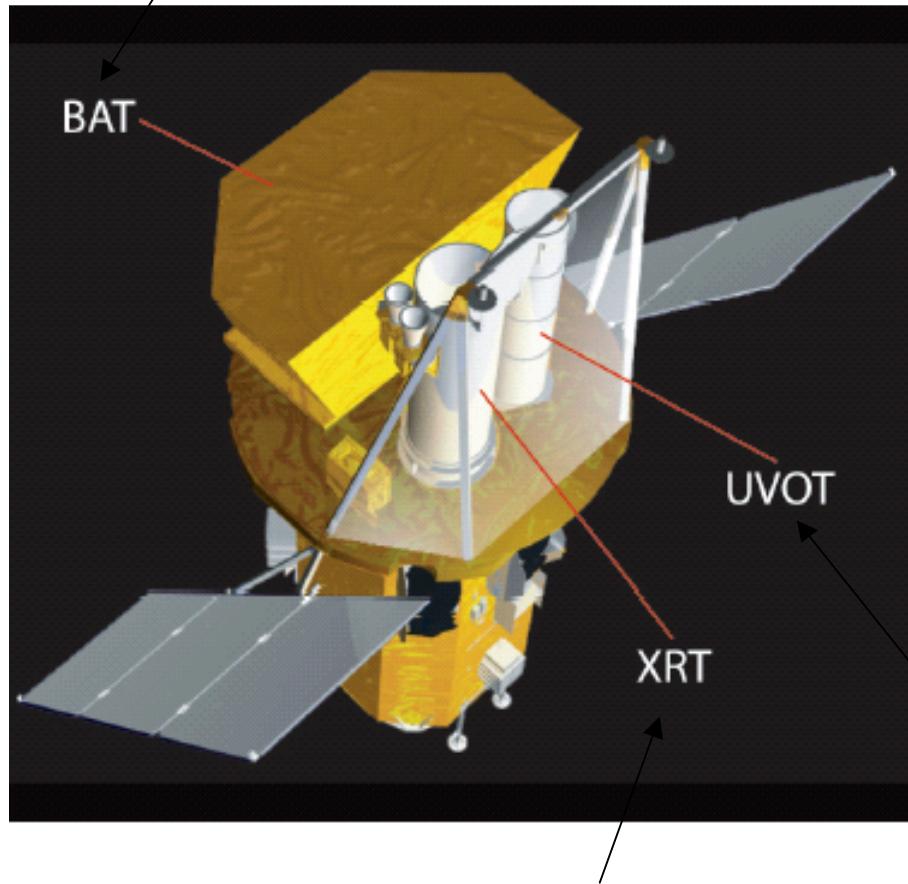
SWIFT

Blasted off on 11/20/2004



Mészáros pan05

BAT: Energy Range: 15-150kev
FoV 2.0 sr, CZT det, coded mask, $\theta\sim5'$
Burst Detection Rate: 100 bursts/yr



XRT: Energy Range: 0.2-10 keV
CCD imager-spectrograph, $\theta\sim5''$

Three instruments

Gamma-ray, X-ray and optical/UV

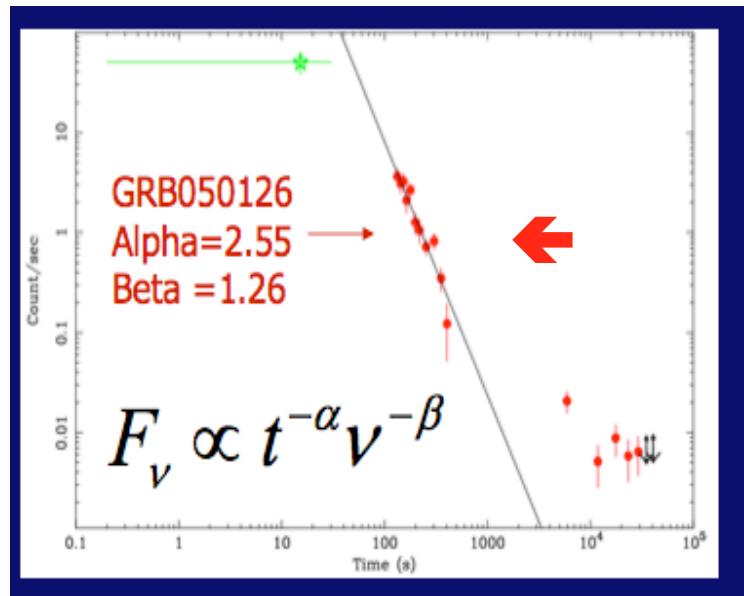
Slew time: 20-70 s !

UVOT: Wavelength Range: 170-650nm
5 filters, 24th mag, grisms, $\theta\sim1''$

SWIFT: New Results

- ~60 new **afterglows** localized since launch
- **Redshifts** for 16 long GRB and 4 short GRB
- $\langle z_{\text{long}} \rangle \sim 2.4\text{-}2.8$, which is 2x BeppoSax distance
(i.e. significantly **fainter & redder**, than B-Sax afterglows!)
- $\langle z_{\text{short}} \rangle \sim 0.3$; $L_{\text{short}} \sim 10^{-2} L_{\text{long}}$; compact merger
- **XR light curves** (10^2s - 10^4s): new features
(both and short) - **steep + shallow decay, flares**
→ evidence for **continued activity?**

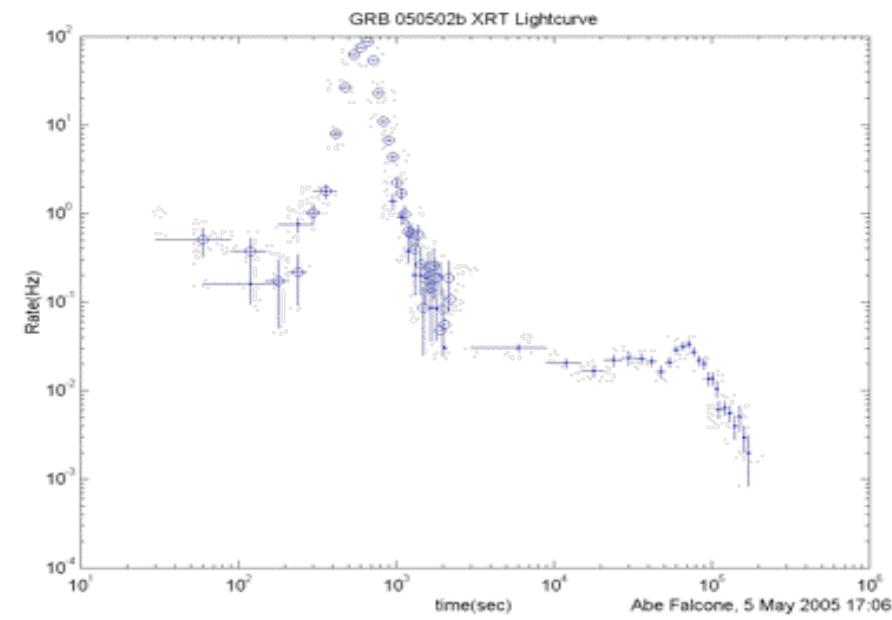
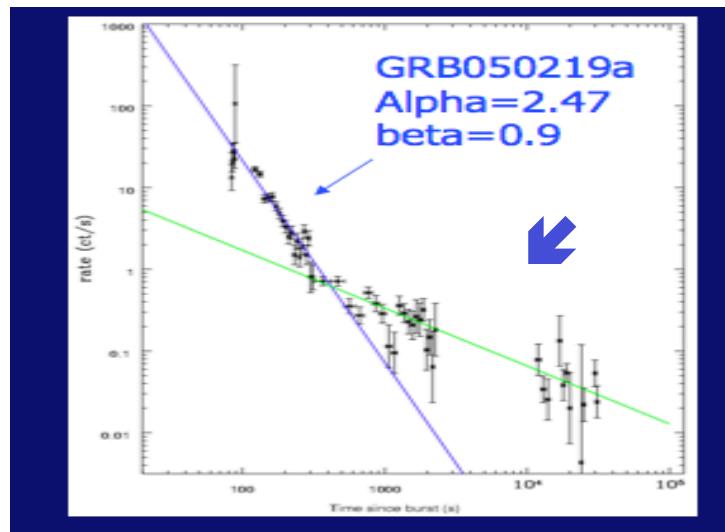
Long Bursts: New Early Features



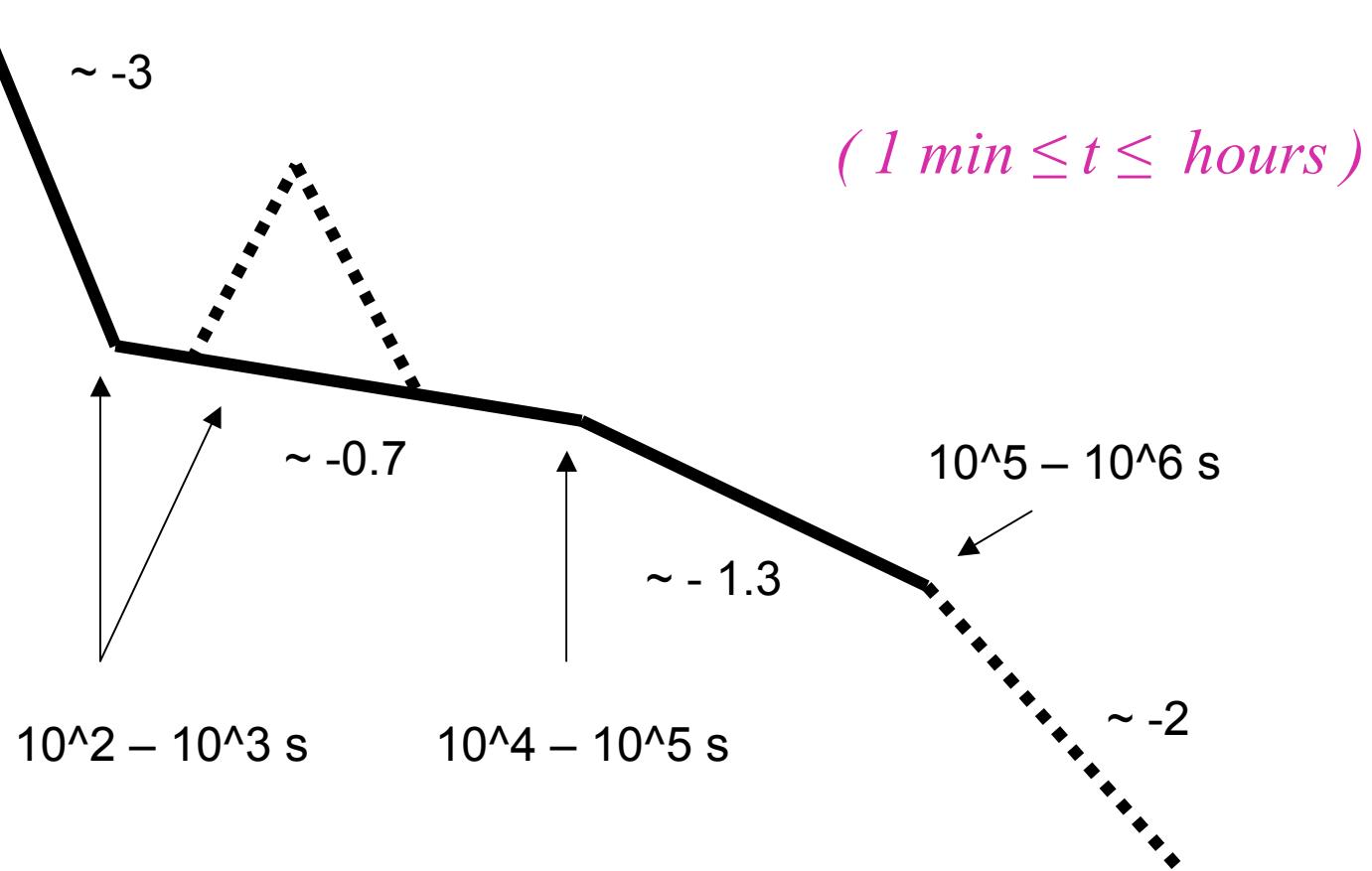
← Early steep drop (100-300 s)

↖ Intermediate shallow decay

↙ Intermediate flares



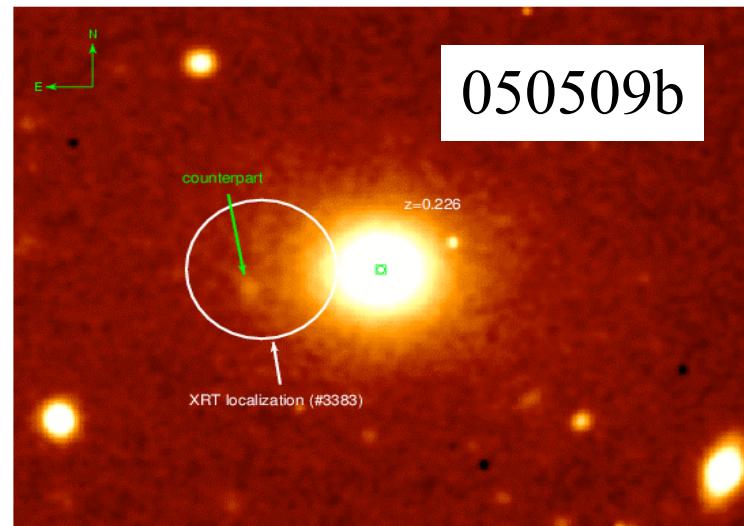
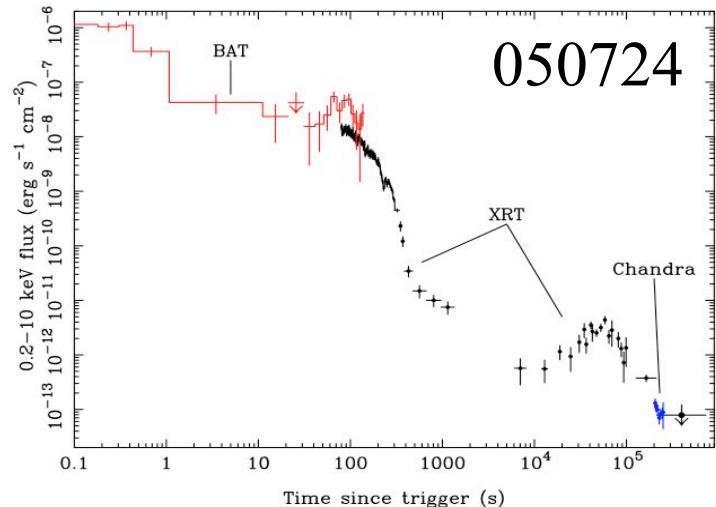
New features seen by Swift : A Generic X-ray Lightcurve?



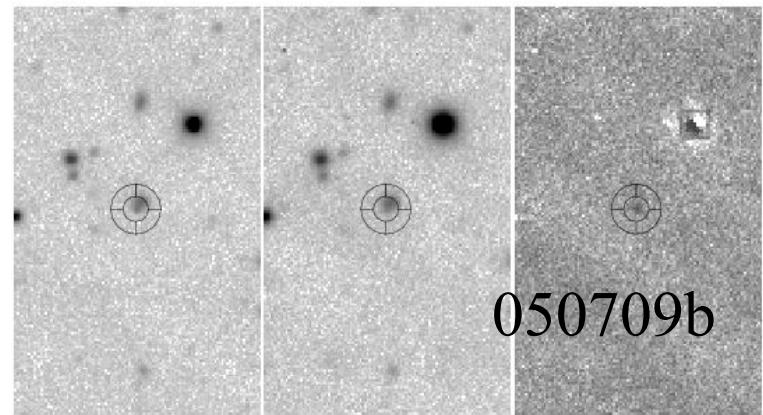
Possible Explanations of long GRB afterglow new features

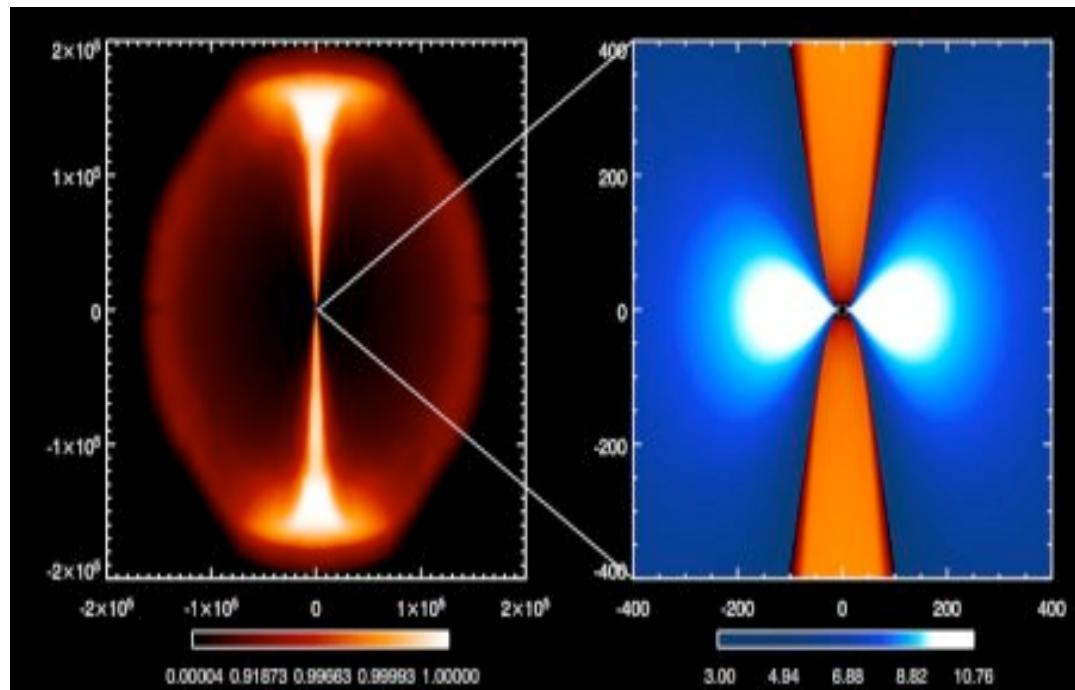
- ***Initial drop:*** likely due to **tail end of GRB** (high latitude emission) : rad'n from $\theta > \Gamma^{-1}$ arrives at $t \sim R\theta^2/2c$ later than from $\theta \sim 0$, is softer by $D \sim t^{-1}$; expect $\alpha = 2 + \beta$, ~ OK
- ***Shallow decay:*** probably “refreshed shocks”, **either** from **Longer** ejection ($t \sim t_{\text{flat}}$) ; **or Short** ejection ($t \sim t_\gamma$), but with range of Γ , e.g. $M(\Gamma) \sim \Gamma^{-s}$, $E(\Gamma) \sim \Gamma^{-s+1}$
- ***Flares:*** likely due to continued central engine activity : main constraints: very sharp rise and decline ($t^{\pm 3} \longleftrightarrow t^{\pm 6}$)

SHORT BURSTS



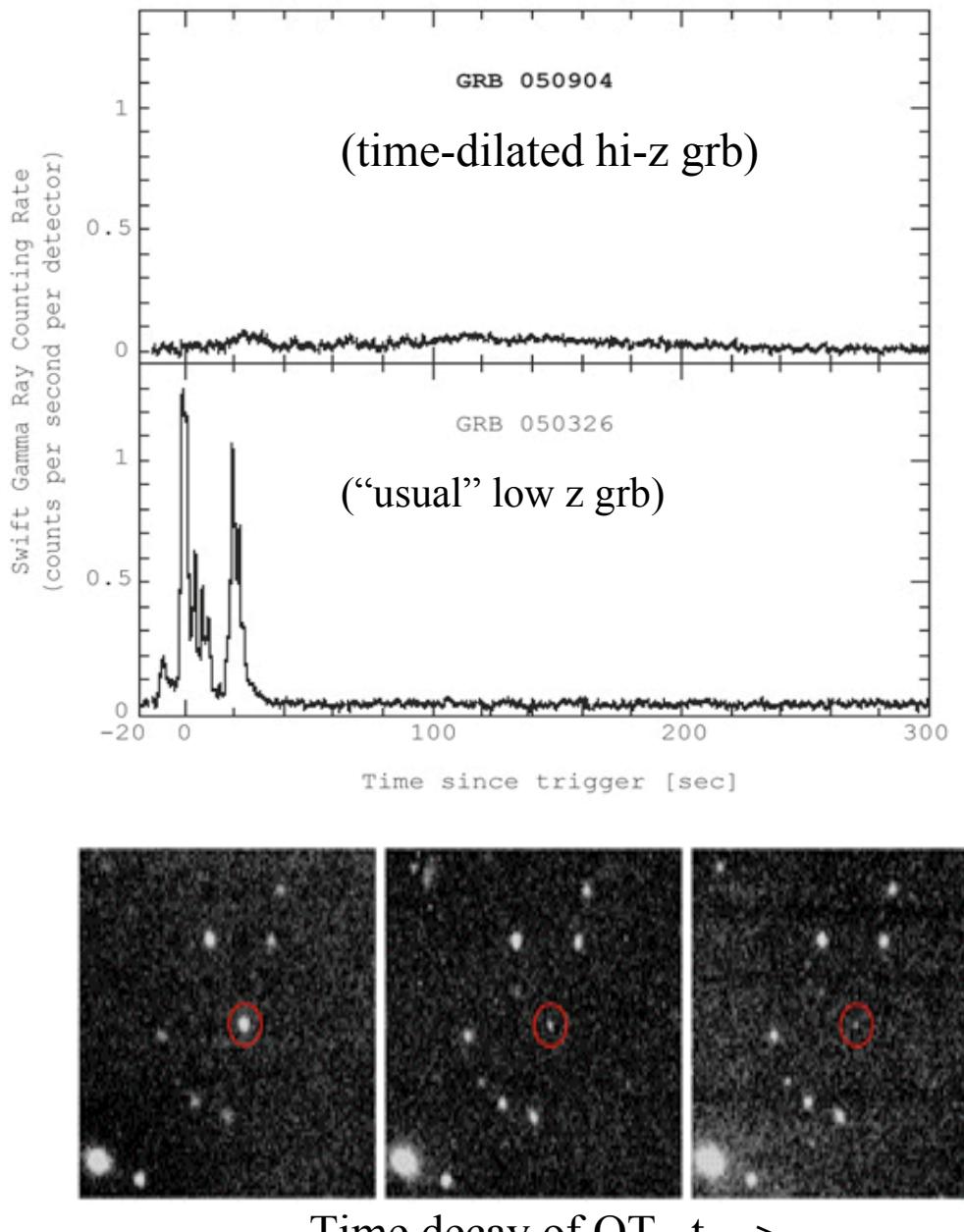
- **Hosts:** E , Irr , SFR
(compat. W. NS merg,
but: some SGR, other?)
- **Redshift :** < 0.1 to > 0.7
- **XR, OT, RT:** yes (mostly)
- **XR l.c.:** similar to long bursts?
(XR bumps too- late engine?)





- ***NS-NS merger movie***
- ***NS-BH merger movie***

Short burst
 paradigm:
NS-NS or
NS-BH
 merger
 ↓
 BH +
 accretion

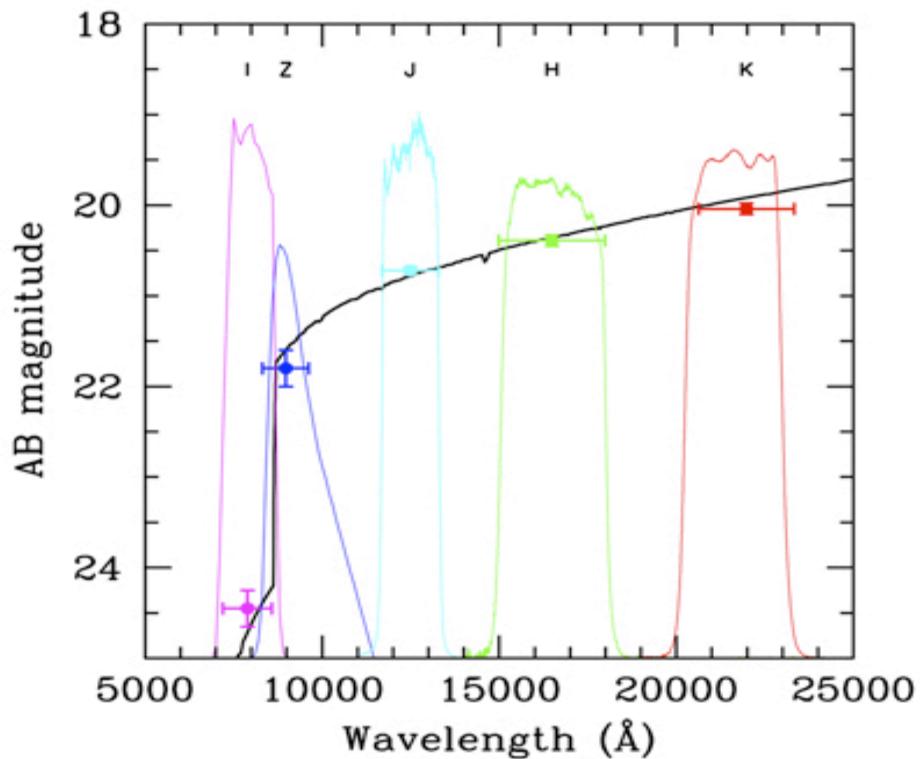


Most distant

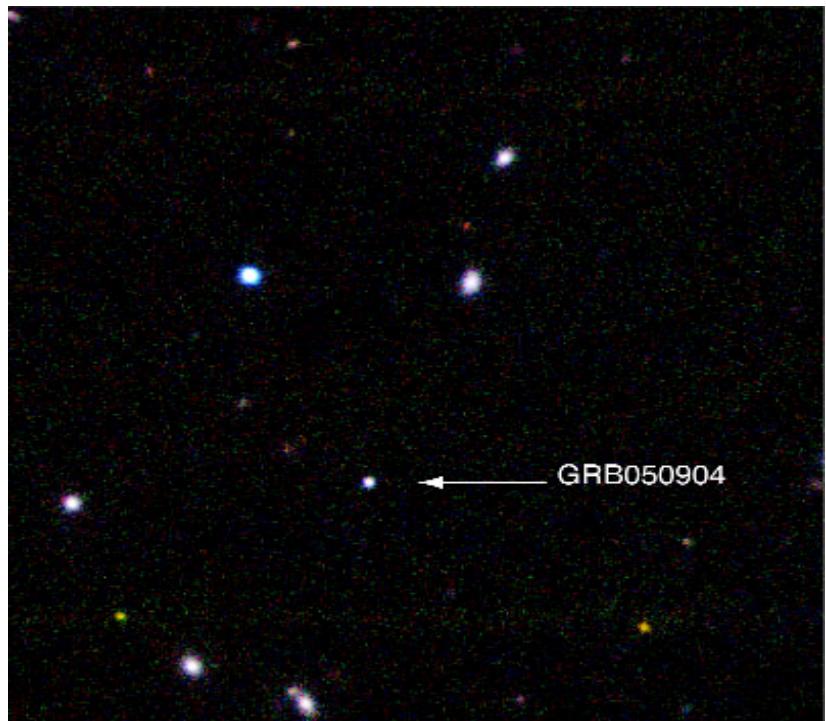
long burst from
Swift ($z=6.29$):
GRB050904

- Discovered/localized by **Swift BAT, XRT, UVOT**
- Prompt robotic ground I,R band **TAROT, P60** upper limits, detection J=17 mag **FUN/SOAR**
→**photometric $z>6$**

GRB 050904



“photometric” $z > 6$: Ly α (1210 Å) abs. cut-off

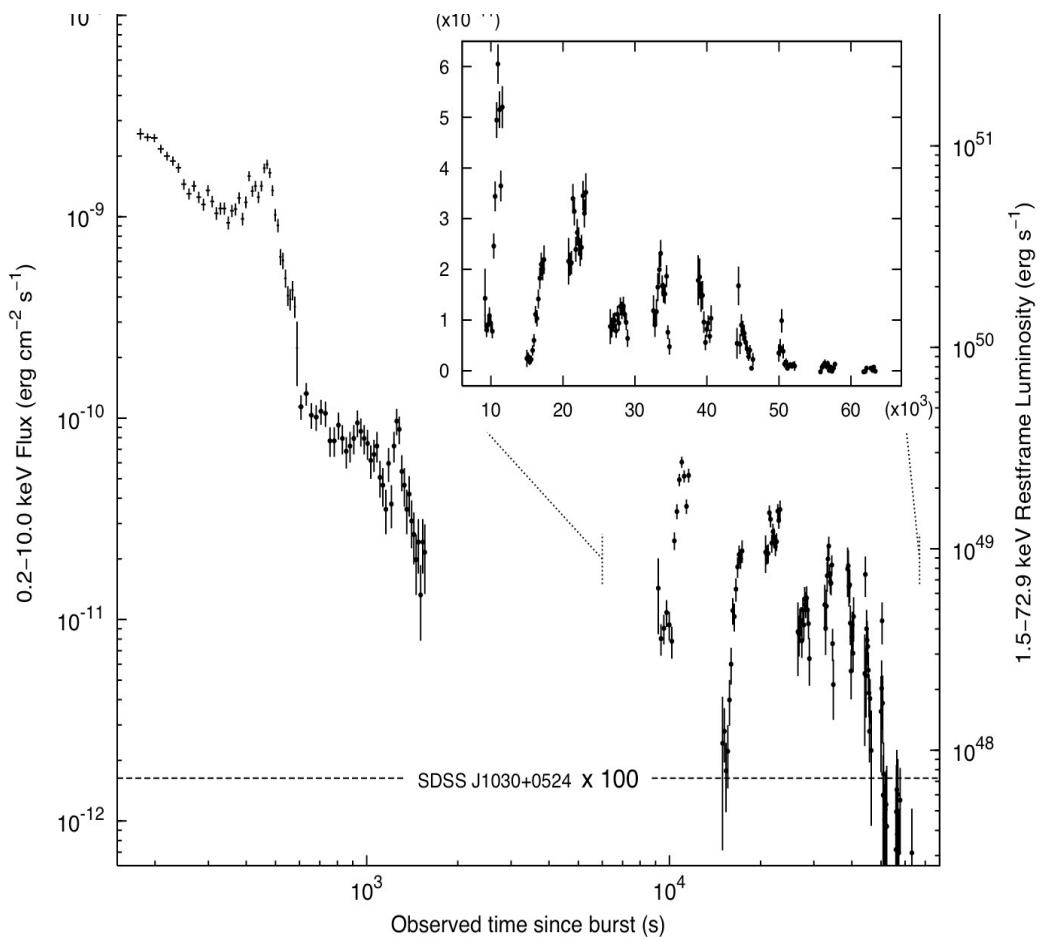


The Distant Gamma-Ray Burst GRB050904
(ISAAC/VLT)



and ... **Subaru** 8.2m telescope spectrum, 3.2 days later: **$z=6.29$!**

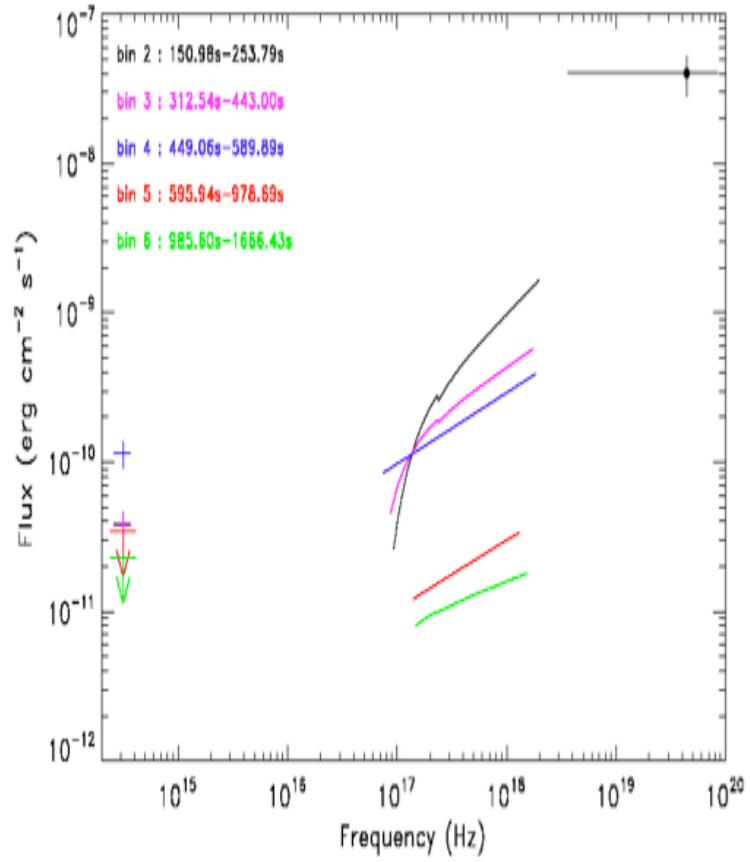
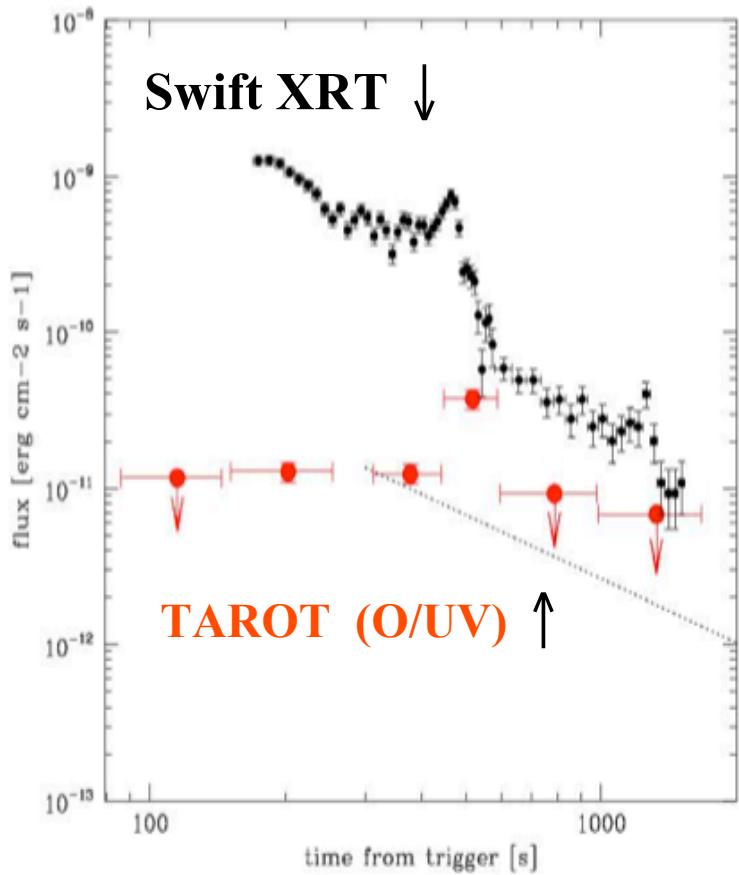
GRB 050904 as an XR beacon



- At a redshift **$z=6.29$**
(~reionization; most distant known known QSR: $z \sim 6.4$)
- GRB 050904 X-ray flux **exceeded** that of the brightest known X-ray QSO SDSS J0130+0524, by up to **$\times 10^5$** , for **days**

← SDSS J0130 (multiplied by 100)

GRB050904: Prompt O/UV flash



- Prompt O/UV flash as bright as 990123 at same z (rev. shock..)
- $E_{\text{iso}} \sim 10^{54}$ erg, similarly very high ;decay similarly steep ($\sim t^{-3}$)
- Observed at 800-1000 nm by TAROT (25 cm tel.!) [Boer et al, astro-ph/0510381]

Conclusions

- Will learn much about GRB (& AGN) in GeV range; many with good photon stats. to 0.1-0.2 TeV
- Will constrain electron acceleration / shock parameters, compactness of emission region (dimension, mag.field,..)
- TeV γ detection: mainly from few/nearby GRB, AGN, SNR
- TeV ν signals: provide complementary info on hadronic cascade components
- UHE ν will allow test of proton content of jets, proton injection fraction, test shock accel.physics, magn. field
- If UHE ν NOT detected in GRB, AGN \rightarrow jets are MHD!
- Probe ν interactions at \sim TeV CM energies
- Constraints on stellar evolution and death, star formation rates at redshifts of first structures
- High z GRB could be probes of “pop III” first gen. Objects
- May test SN-GRB connection & transition